1998

Spiders and other arthropods in old growth versus logged coast redwood stands

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SPIDERS AND OTHER ARTHROPODS IN OLD GROWTH VERSUS LOGGED COAST REDWOOD STANDS

A THESIS SUBMITTED TO
THE FACULTY OF THE DIVISION OF SOCIAL SCIENCES
IN PARTIAL FULFILLMENT FOR THE DEGREE OF
MASTERS OF SCIENCE

DEPARTMENT OF ENVIRONMENTAL STUDIES

BY
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DECEMBER, 1998

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ABSTRACT

SPIDERS AND OTHER ARTHROPODS IN OLD GROWTH VERSUS LOGGED COAST REDWOOD STANDS

by Terrence R. Willett

This study, conducted in the Santa Cruz Mountains of California, provides data on the abundance and diversity of litter spiders and other arthropods in three redwood forest conditions: old growth, second growth, and tree farm. It is believed that litter spiders are linked to and reflect habitat structure and prey abundance. Canonical correlation analysis showed significant declines in spider and other arthropod diversity and abundance with increased logging, suggesting that selective harvesting techniques do not maximize litter arthropod diversity or abundance. Further, there was an absolute and relative increase in nocturnal spiders and detritivores in unlogged sites, suggesting that guild structure of spiders and other arthropods can indicate forest recovery from logging disturbance. This study also identifies common redwood litter spiders, describing a baseline for forest management. These findings strengthen the case for including soil arthropods in redwood forest monitoring and assessment and for the preservation of undisturbed forest areas.

ACKNOWLEDGMENTS

I would like to thank the persons and organizations without whom this project could not have been realized. First, I thank my thesis committee members, Dr. Trulio, Dr. Carrothers, and Dr. Stecker who took the time to advise, provide supplies, and most importantly review drafts of this paper. Thanks also to Darryl Ubick and Dr. Griswold of the California Academy of Sciences for assisting in identification and preserving a portion of my collection. Also, I thank: Dr. Bros for her statistical advice; Dr. Moldenke and Dr. Launer for discussing the project design with me; my classmates who supported me through several incarnations of this project during the developing stages most notably Mark Jordan, Karen Rosen, Shannon Stout, Stan Vaugn, and Chris Wellise; my dedicated field volunteers including Andy Vargas, Pam Cassar, Elise Delassuegus, and Shanti Gillis as well as the Spring 1997 Cabrillo College Ecology Class; Verl Klausen and Kathy of the Sempervirens Fund for contact information; Big Basin State Park and its Resource Ecologist George Gray; RedTrees Properties and its forester Dave Hermann and Fred Keesaw the caretaker for allowing me access to their lands, guiding me around their properties, and freely providing necessary historical information; the rangers of Big Basin State Park for supplying guidance and information, camping, parking, and medical assistance; the California Native Plant Society for helping fund this project with the Doc Burr Graduate Research Grant; the San José State Entomology Department for supplying collection supplies; and my brother, Tom Willett, and Calico Cook for storing backup copies of my data and drafts; and Michelle Hayward for editing advice. Most heartily, I thank my partner, Jennifer Cross, who has supported and assisted in every step of the process by reading drafts, assisting in the field with site surveys and vegetative sampling and in the laboratory with identifying and cataloging arthropods, and most important for providing emotional support and encouragement during the darkest moments. Finally, we thank the elusive forest fauna for their sacrifice. In return I will tell their tale, not just once or twice, but thrice by thrice, until all who have heard the lore know that these ancient cathedrals are home to more than deer and eagles but also to spiders and beetles and other small creatures greatly needed.

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INTRODUCTION

Research shows that forest litter spider community structure and guild composition relates to and is indicative of: 1) habitat structure and 2) prey abundance (Clarke and Grant 1968, Huhta 1971; Uetz 1976, 1979, 1992; Simmonds, Majer, and Nichols 1994; Mciver, Moldendke, and Parsons 1992, Pettersson *et al.* 1995, Pajunen *et al.* 1995). In the interest of improving forest assessment and testing the impacts of forestry, this study explored litter spider and other litter arthropod diversity, abundance, and guild structure as indicators of the changes in the soil arthropod community in relation to logging activity in a redwood forest in the Santa Cruz Mountains of California.

Deforestation

Global Effects

Of all the disturbances that may affect a forest, anthropogenic deforestation through extensive logging and clearing for development, agriculture, and firewood is the most severe (Miller 1989; Wilcove 1989; Norse 1990; Devall 1993, Kricher and Morrison 1993; Bryant, Nielsen, and Tangley 1997). In a survey of global forest conditions, Bryant, Nielsen, and Tangley (1997) found that the forest cover has been reduced from 62,203,000 square kilometers to 33,363,000 square kilometers, a 54% loss, in the past 8,000 years. About 4,500,000 square kilometers of forest, 7% of the original cover, were lost between 1960 and 1990. Bryant, Nielsen, and Tangley estimated that "commercial logging is by far the greatest danger" (1997, 15) to remaining wild

forests. Other factors contributing to forest loss include clearing for agriculture, mining, petroleum and natural gas exploration, hydroelectric dams, and urban development.

Further, forest species that have evolved with natural disturbances such as fire and flooding most probably have not evolved adaptations to the recent human-caused disturbances of their cycles. Many adverse consequences follow from these human generated disruptions, particularly habitat loss, which is thought to be the primary reason for species extinction. In general a 90% reduction in habitat leads to a loss of half the occupying species (MacArthur and Wilson 1967; Wilson 1992). Specifically, the California Department of Forestry has stated that the "major impact on the fishery habitat within the forested areas of California is logging and logging-related road building"(1979, 167) and has probably led to the endangerment of many anadromous fish species. Forest clearing can also lead to the erosion of soil and the destabilization of slopes, which impacts water supplies and fish habitats (Waring and Schlesinger 1985; Kimmins 1987), can contribute to changes in local climate and hydrology (Kimmins 1987), lowers global carbon fixation (Waring and Schlesinger 1985), and can homogenize within stand carbon dioxide concentration stratification, which impacts seedling growth (Bazzaz and Williams 1991). Forest loss also eliminates non-timber forest resources such as medicines, pigments, oils, fibers, edible fungi, nuts and fruits, æsthetic and cultural resources, and sources of employment (Norse 1990; Wilson 1992).

California Redwoods

While tropical deforestation is often viewed as the world's most critical forest issue, temperate deforestation is no less extensive (Norse 1990; Devall

1993; Bryant, Nielsen, and Tangley 1997). Coast redwood (*Sequoia sempervirens*) forests only occupy a coastal strip 5 to 35 miles wide between 100 and 2,000 feet in elevation from southwest Oregon to central California (Barbour *et al.* 1993). Extensive logging has reduced old growth redwood forests from 2 million acres in 1850 to about 74 thousand acres by the early 1990's (Snyder 1992, Barbour *et al.* 1993). This remnant continues to decline as the last privately owned old growth redwood is being logged or is in danger thereof in the Headwaters forest of Humboldt County.

To counter this trend, several strategies must occur simultaneously including reducing the consumption of forest products, eliminating socio-economic conditions that favor deforestation, revising forestry practices to manage redwood forests on a longer time scale, and protecting remnant undisturbed stands (Harris 1984; Zinke 1988; Norse 1990; Barbour *et al.* 1993; Devall 1993; Noss 1993; Kricher and Morrison 1993; Ferguson 1996). In addition, attempting to restore disturbed habitats to a level of full ecosystem functioning is now recognized as an important conservation strategy in addition to preservation and sustainable management (Baldwin, de Luce, and Pletsch 1994).

Forest Restoration

Marsh wrote that restoration is when humans "aid [nature] in reclothing the mountain slopes with forests and vegetable mould [sic], thereby restoring the fountains which [nature] provided to water them" (1965, 35). More specifically, restoration ecology seeks to bring the functioning of a disturbed or degraded ecosystem to the level of an undisturbed system with the indigenous communities, structures, and functions intact (Jordan, Gilpin,

and Aber 1987). In planning a restoration project, the restorationist often sets success criteria based on knowledge of the original biotic and abiotic elements of the ecosystem. Measurable parameters derived from the sampling of species, habitat structure, and ecosystem processes serve as the foundation for restoration goals. Since every conceivable parameter cannot be sampled, restorationists must sample specific attributes that indicate the functional state of the ecosystem.

For the biotic component, a particular taxa, usually a conspicuous variety, often serves as an indicator of the state of the original biotic system. "Indicators are often used as an index of environmental conditions that are too difficult, inconvenient, or expensive to measure directly" and "can portray responses to cumulative effects of natural and human-induced environmental conditions" (Morrison and Marcot 1995, 150). However, declines in indicators do not always reflect degradation of habitat. Also, the value of indicator species or communities is only in relation to the extent of our knowledge about them and their responses to changes. While biotic indicators have limitations, they are quite useful. For example, the endangered Northern Spotted Owl (*Strix occidentales*) serves as an indicator of mature forest conditions in the Pacific Northwest (Ehrlich, Dobkin, and Wheye 1992; Kricher and Morrison 1993).

Understory vegetative succession is a common indicator of recovery for forest ecosystems (Muldavin *et al.* 1981). Since this vegetation forms the base of food webs, these plants have a large impact on the nature and extent of recovery. But these plants may take years to respond to changes during the process of restoration, which reduces their value as indicators of rapid changes in the restoration process. Restorationists have investigated the usefulness of other indicators of forest recovery such as lichens (Anonby,

1991), carabid beetles and birds (Haila *et al.* 1994), birds only (Morrison 1992; Adams and Morrison 1993), ants (Puntilla *et al.* 1991, 1994; Andersen 1993: Andersen and Sparling 1997), rodents (Haim and Izhaki 1994), bats (Gellman and Zielinski 1996), dragonflies (Clark and Samways 1996), terrestrial invertebrates (Jansen 1997), and stream invertebrates (Stone and Wallace 1998). Each of these taxa are conspicuous and most have predictive value in assessing recovery and management strategies. However, Moldenke and Lattin (1990) pointed out that soil arthropods, such as mites and collembola, may be the most important constituents of the forest due to their role in decomposition and nutrient cycling, as well as acting as vectors to inoculate roots with mycorrhizal fungi (see also Crossley, 1977; Peterson and Luxton 1982).

Arthropods as Indicators

In forests, soils and their below ground processes and species complement can constitute the most active and productive portion of the systems. Decomposition and nutrient cycling mostly occur in the soil while 50% to 90% of primary production can be below ground (Brown and Gange 1990). Roots, fallen leaves and lichens, fallen snags and the bodies of animals and protozoans are decomposed primarily by bacteria and fungi, collectively referred to as the microflora (Coleman and Crossley 1996; Reichle 1977). Smaller arthropods, primarily mites and collembola, in turn feed on the microflora. These organisms have been shown to affect and regulate microbial growth, succession, competition, the transportation of microbial propagules to uncolonized microhabitats, and the ability of bacteria and fungi to form obligate symbiotic associations with plants (Coleman and Crossley

1996; Wood 1995; David *et al.* 1991; Moldenke 1990; Wallwork 1983; Hanlon and Anderson 1979; Shaw 1985; Verhoef and deGoede 1985; Anderson *et al.* 1985; Visser 1985; van der Drift and Jansen 1977; Reichle 1977; Ausmus 1977). Microarthropods are especially important agents in slowly decomposing litter dominated by fungi such as is found in temperate forests (Wood 1995; Coleman and Crossley 1996), although their role may be more as an indirect catalyst for decomposition (Peterson and Luxton 1982).

Kremen *et al.* (1993) suggested that because of their importance, their diversity, and ease of sampling at gross taxonomic levels, terrestrial arthropods should be included in all inventories and monitoring projects. Soil fauna may act as sensitive indicators of forest conditions due to their rapid generation time and the observation that "the different species of soil arthropods respond to environmental gradients, each in its own way" (Moldenke and Lattin 1990, 410). Lattin and Moldenke (1990) noted, for example, that moss lacebugs tend to be represented by more flightless species in mature forests, perhaps because of the relative stability of these stands and the subsequent lack of selection for dispersal abilities. As another example, Økland (1996) found that mycetophilid flies had increased species richness in unlogged forests with wood in all decay stages and full tree cover.

Many of the aforementioned indicators such as flies and small mammals reflect, somewhat exclusively, either the habitat structure, the presence of a primary producer food base, or the presence of a saprophagous food web system. Crossley (1977) suggested that a connection exists between detritivore and herbivore trophic levels through predators. As both of these food chains are essential in terms of providing habitat and maintaining nutrient cycling, a single indicator taxon that reflects both these webs could be particularly valuable.

Schowalter (1990) found reduced arthropod predator diversity and abundance in planted stands, or tree farms, as compared to old-growth forest stands. This suggests that not only are arthropod predators a link between detritivore and herbivore food chains but that they can also show measurable responses across disturbance gradients. In selecting an indicator for restoration purposes, the ability to discriminate between levels of disturbance could aid the determination of a given site's state and stage of recovery.

Centipedes, ants, and spiders are the most common soil predators observable by the naked eye. Puntilla *et al.* (1991, 1994) found differences in ant species composition between old growth and managed forests. Studies show that spider guild composition changes with the abundance of soil arthropod prey and stage of recovery after disturbance, with an altered guild composition (Clarke and Grant 1968, Huhta 1971; Uetz 1976, 1979, 1992; Simmonds, Majer, and Nichols 1994; Mciver, Moldendke, and Parsons 1992, Pettersson *et al.* 1995, Pajunen *et al.* 1995). In his review, Uetz (1990) concluded that the majority of such research shows the abundance and species richness of spiders to be highest in late seral stages or in vegetatively heterogenous habitats and that therefore spiders are an ideal organism to test hypotheses about the factors underlying gradients in species diversity. Some of these factors include succession and moisture gradients (Mciver, Moldendke, and Parsons 1992; Pajunen *et al.* 1995), prey abundance, and habitat structure (Uetz 1990; Gunnarsson 1990; Spiller and Schoener 1994; Sundberg and Gunnarsson 1994, Pettersson *et al.* 1995).

Litter spider community structure is directly affected by: 1) habitat structure and 2) prey abundance. These in turn affect microbial ecology, nutrient cycling and mycorrhizal associations, which influences plant growth,

succession, and recovery after disturbance. While microbes (bacteria and fungi) or microarthropods (mites and collembola) are valid indicators of these successional processes, spiders are much easier to sample and identify as they are larger and their taxonomy greatly more developed. Microbes must be extracted and cultured with fairly complex techniques and then separated into species largely on the basis of their degree of similarity of DNA sequences. The standard threshold for placing microbes into different species is no more than 70% similarity (Coleman and Crossley 1996; Wilson 1992). However, this is problematic as some organisms show speciation even with 98% similarity in DNA sequences, such as between humans and chimpanzees (Coleman and Crossley 1996; see also Wilson 1992 for a discussion of the definition of species and its complications). Similar problems with extraction and identification of microarthropods exist (Stecker, personal comment). Litter spiders can better serve the purpose of indicating forest conditions not only because of their connection to vegetative structure and soil processes but also because they are practical to sample in the context of restoration monitoring or other forest management assessments.

Recent Research

Three important recent studies are Mciver, Moldendke, and Parsons (1992), Pajunen *et al.* (1995), and Hoekstra *et al.* (1995). Mciver, Moldendke, and Parsons (1992) sampled spiders in the H. J. Andrew Experimental Forest in western Oregon, which is primarily dominated by Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*). The study by Pajunen *et al.* (1995) occurred in a southern Finnish taiga dominated by spruce (*Picea abies*) and pine (*Pinus sylvestris*). Hoekstra *et al.* (1995)

studied guilds of litter arthropods in coast redwood (*Sequoia sempervirens*) forest.

Mciver, Moldendke, and Parsons (1992) and Pajunen *et al.* (1995) sampled spiders with pitfall traps in various forest conditions from clear-cuts to managed or second growth stands to old-growth remnants and found clear associations between spider guild type and forest conditions at various levels of disturbance and across moisture gradients. Specifically, both studies found visual pursuit spiders such as gnaphosids and lycosids to have higher abundances in recently cut areas while "sit and wait" spiders such as linyphiids and trapdoor spiders have higher abundances in more mature stands.

Hoekstra *et al.* (1995) sampled soil arthropods extracted with Berlese funnels in old growth and second growth areas in Big Basin State Park and recently harvested areas in the Red Trees tree farm. The second growth and tree farm areas had been cut eighty years ago and the tree farm was cut three additional times in the past twenty years. They used a "higher-taxon" approach (Williams and Gaston 1994) to assess species richness. Rather than using a single species as an indicator or expending the effort to key to the species level, which can be quite difficult with microarthropods, the guild, family, or order level of classification is often used to assess community richness and abundance. Hoekstra *et al.* (1995) found the abundances of panphytophages and predators to be significantly lower in the tree farm than in the second growth or old growth areas while these latter two conditions were not significantly different from each other. These studies reinforce Uetz's (1990) observation that increased spider species richness and abundance occurs in later successional, more complex habitats across many studies and illustrate the potential value of spiders as bio-indicators in forest management.

Not all studies concur with these findings. In a study of boreal canopy

invertebrate communities in Sweden, Pettersson *et al.* stated that "forest floor studies often show little or no difference in faunal composition, abundance, or diversity between natural and managed stands...[and that]... studies of tree- and fungus-living invertebrates...often show great differences because many of those invertebrates depend on dead wood" (1995, 61). This study did not cite Uetz's (1990) review or the Mciver, Moldendke, and Parsons (1992), Pajunen *et al.* (1995), or Hoekstra *et al.* (1995) studies and seemed to draw its conclusion from a review of studies in Scandinavian countries (note that the Pettersson *et al.* (1995) study was accepted three weeks before the Pajunen *et al.* (1995) study was accepted). Because Pettersson *et al.*'s (1995) review is limited in its geographic focus, the value of a forest floor study in California should not be discounted.

Another study that indirectly challenges the use of litter spiders as indicators of forest ecosystem functioning found that the "interaction between intermediate predators (web spiders) and herbivores is weak" (Spiller and Schoener 1994, 194) as compared to top predators such as lizards in the islands of the Bahamas. The implication is that lizards rather than spiders would be a better indicator for the Bahaman food web and more generally that a top predator would have a stronger effect on herbivores than spiders. However, animals that feed on spiders in redwood forests are not always the top predators and may themselves be prey, complicating the applicability of the Bahamas study to a redwood forest ecosystem. Also, as noted earlier, spiders provide a connection not only to herbivores, but also to detritivores and thus to nutrient cycling and mycorrhizal inoculation, which are important considerations in forest restoration. While animals higher on the food web remain useful indicators, litter spiders could provide a glimpse into saprophagous and phytophagous components of the ecosystem simultaneously and may give valuable insight into the progress of redwood forest recovery from logging disturbance.

Study Objectives

This study explored the community composition, abundance, and diversity of litter spiders and other arthropods in a redwood forest in old growth, second growth, and tree farm conditions. A primary goal was to determine whether spider and other arthropod diversity and abundance changed with increased logging. Also, it was expected that guild structure would change across the logging gradient so that guild structure of spiders as well as other arthropods would indicate forest conditions. Data from this study provides information as to what patterns to expect as sites recover from logging and whether selective harvesting techniques maintain litter arthropod communities in a state similar to nearby old growth.

This thesis work also tested whether spider and other arthropod diversity or abundance varied with their distance from the nearest trail or fire road. In addition, this study identified some of the spiders found in central coast redwood forests to help provide baseline data for management endeavors such as restoration projects.

METHODS

Study Area Description

The study took place in three areas in the Santa Cruz Mountains of California in and around Big Basin State Park. The vegetation composition is a mixed evergreen forest composed primarily of redwoods (*Sequoia sempervirens*), Douglas fir (*Pseudotsuga menziesii*), and tanoak (*Lithocarpus densiflora*). Logging began in the Santa Cruz Mountains after the Gold Rush when humans felled trees for timber, fuel for lime kilns, and for agriculture (deVries 1978). The forest surrounding Big Basin had mostly been cut by the early 1900's when the 2500 acre old growth remnant, 800 acres of chaparral, and 500 acres of cut or burned land became a protected State Park in 1902 (Meadow 1950, Lowry and Verardo 1973, deVries 1978). Subsequent expansions of the Park included previously logged areas within Park boundaries. The tree farm, owned by Red Trees properties since the mid-1970's, had been logged early in the century and three times since prior to the study. The most recent cut in the study area occurred in 1990 and the next cut is scheduled for 2002 (Dave Hermann, personal communication).

The study areas were in the Santa Cruz Mountains northwest of the city of Santa Cruz and southwest of the city of San José (see Figure 1). Two of the study areas were in Big Basin State Park and one was near Waterman Gap (see Figure 2). One study area in the Park consisted of an old growth stand along Gazos Creek Road just to the west of its intersection with the Middle Ridge fire road (approximately 37° 11'00" latitude, 122° 13' 43" longitude). The other study area in the Park was a second growth stand logged 80 to 100 years

ago on the Howard King Trail beginning at the transition from old growth to second growth (approximately 37° 10'00" latitude and 122° 13' 53" longitude) (see Figure 3). The third area, representing a selectively harvested tree farm condition, was to the northeast of Big Basin State Park near Waterman Gap (approximately 37° 12' 43" latitude and 122° 9' 20" longitude) (see Figure 4).

The three areas were chosen in an attempt to capture variation due to logging history while reducing variation due to aspect, elevation, distance from coast, latitude, and general soil composition. The areas were also in proximity to the areas sampled by Hoekstra *et al.* (1995) so that findings might most easily be related to that study.

The mean aspect of the sites within each of the three areas were not significantly different ($F(2,43)=1.097$, $p=0.34$) and were generally westward. The areas had similar elevations with the old growth around 1300 feet (400 meters), second growth around 1400 feet (425 meters), and the tree farm around 1200 feet (360 meters).

Distances from the coast, measured as the raven flies from the outlet of Cascade Creek (37° 8' 9" latitude by 122° 24' 48" longitude), were fairly similar with the old growth at 6.5 miles (10.4 km), second growth at 5.7 miles (9.2 km), and the tree farm at 11.1 miles (17.9 km).

Also, all areas were near a latitude of 37°. Latitude is important as redwood communities farther north change in plant composition, increasing, for instance, in Coast Hemlock (*Tsuga heterophylla*) and Rhododendron (*Rhododendron macrophyllum*) (Hickman 1993; Lyons, Cooney-Lazaneo, and King 1988).

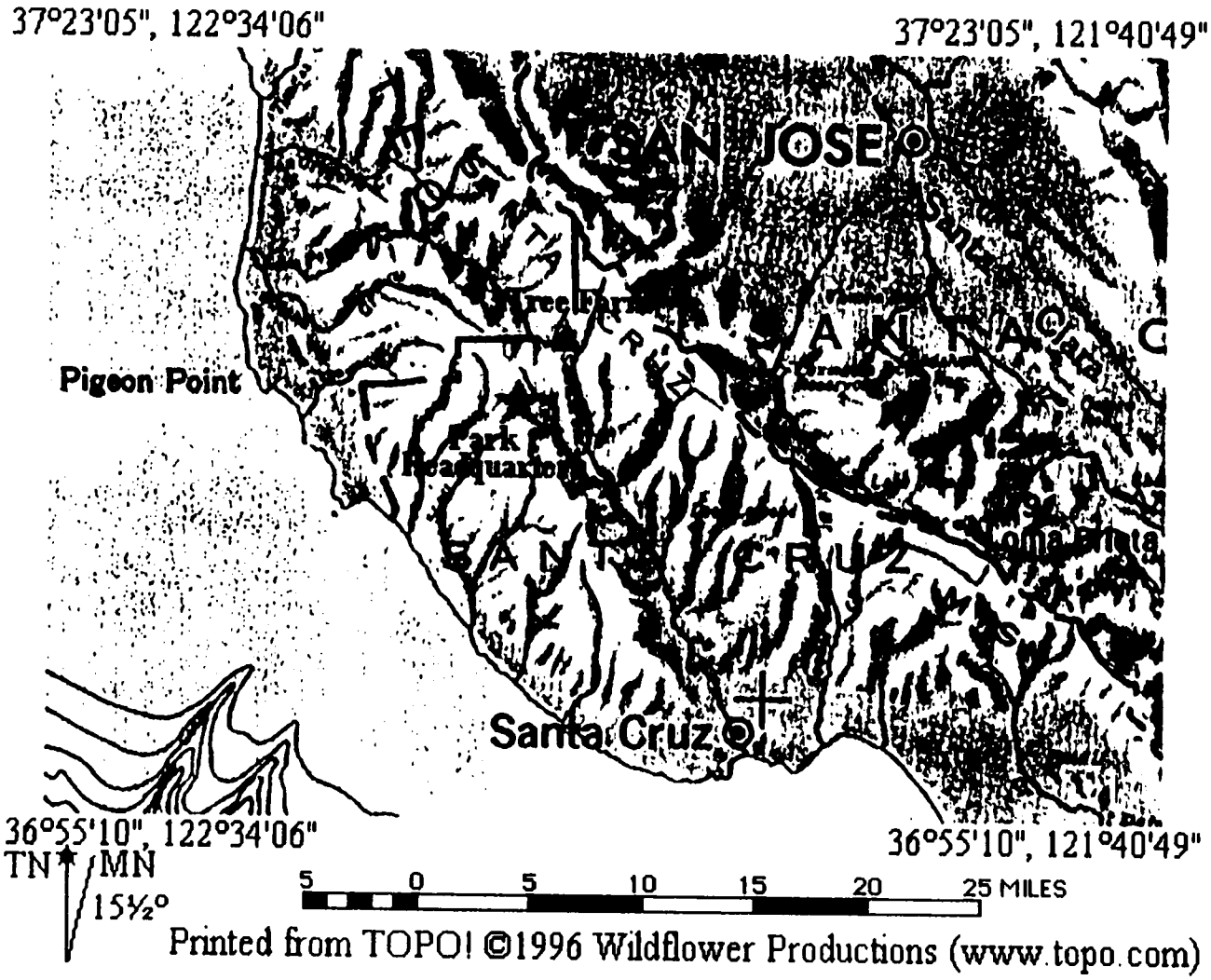

Figure 1.—Study Areas Relative to the Cities of Santa Cruz and San José

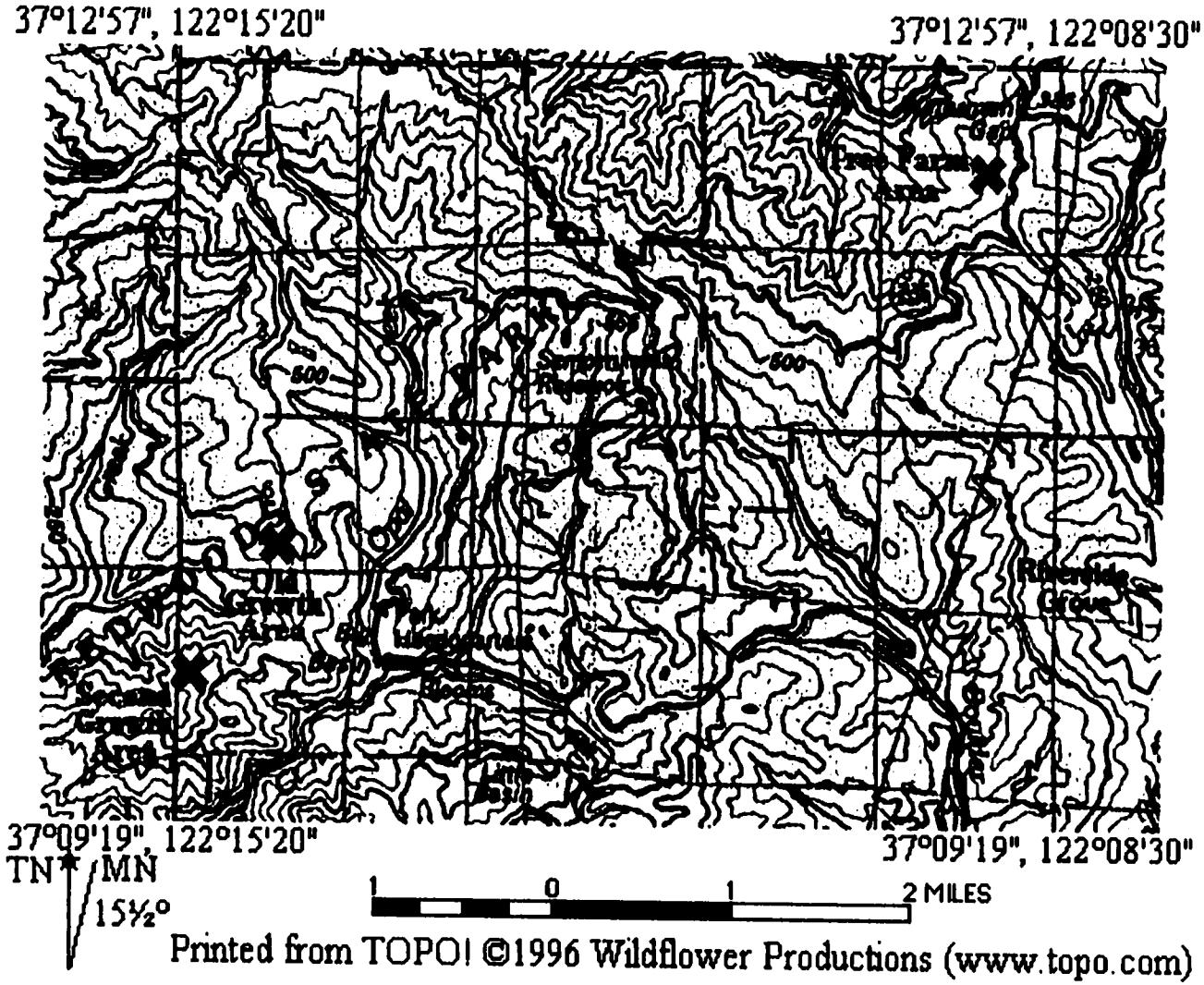

Figure 2.—Locations of Study Areas in the Santa Cruz Mountains

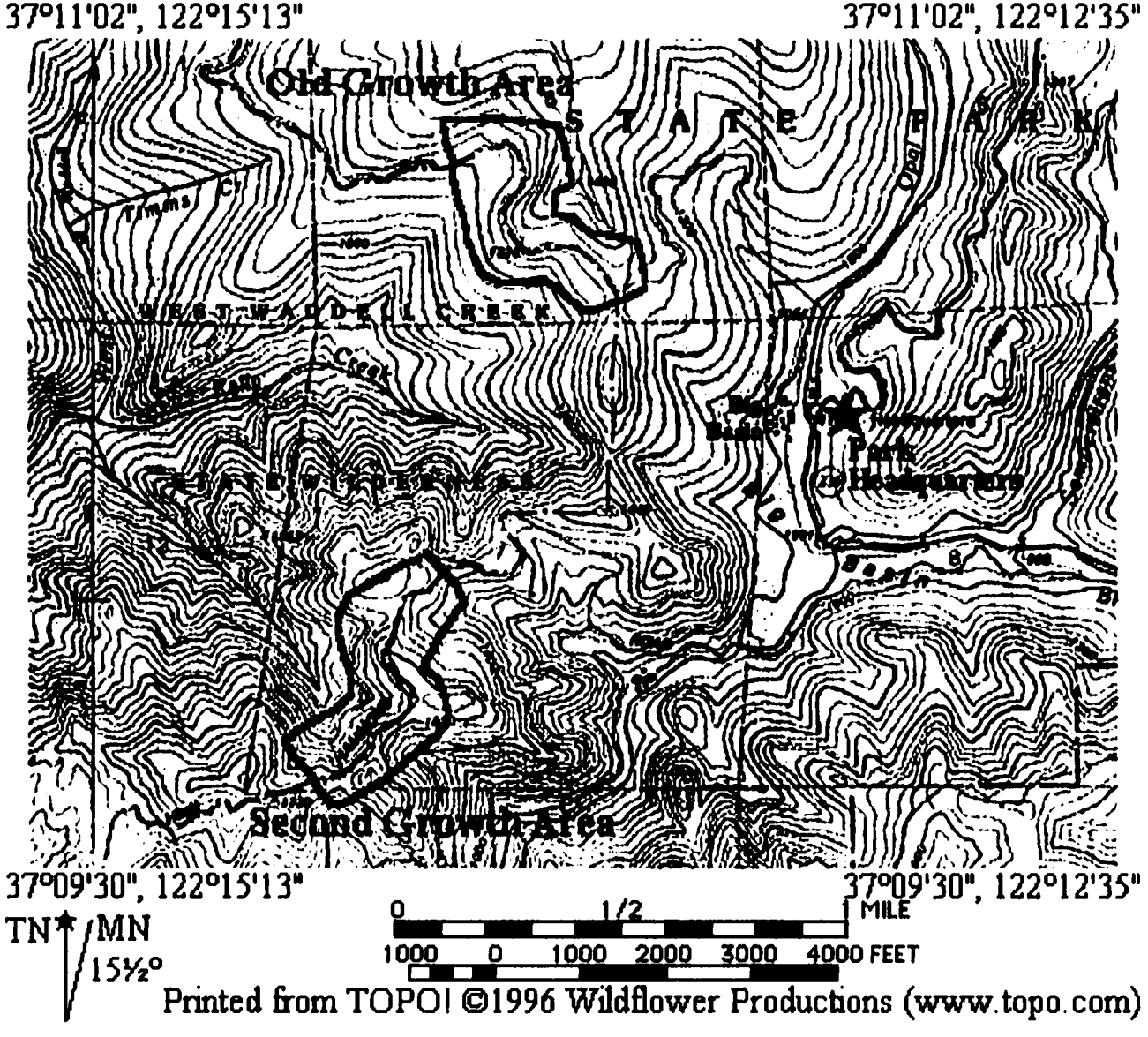

Figure 3.—Old Growth and Second Growth Study Areas

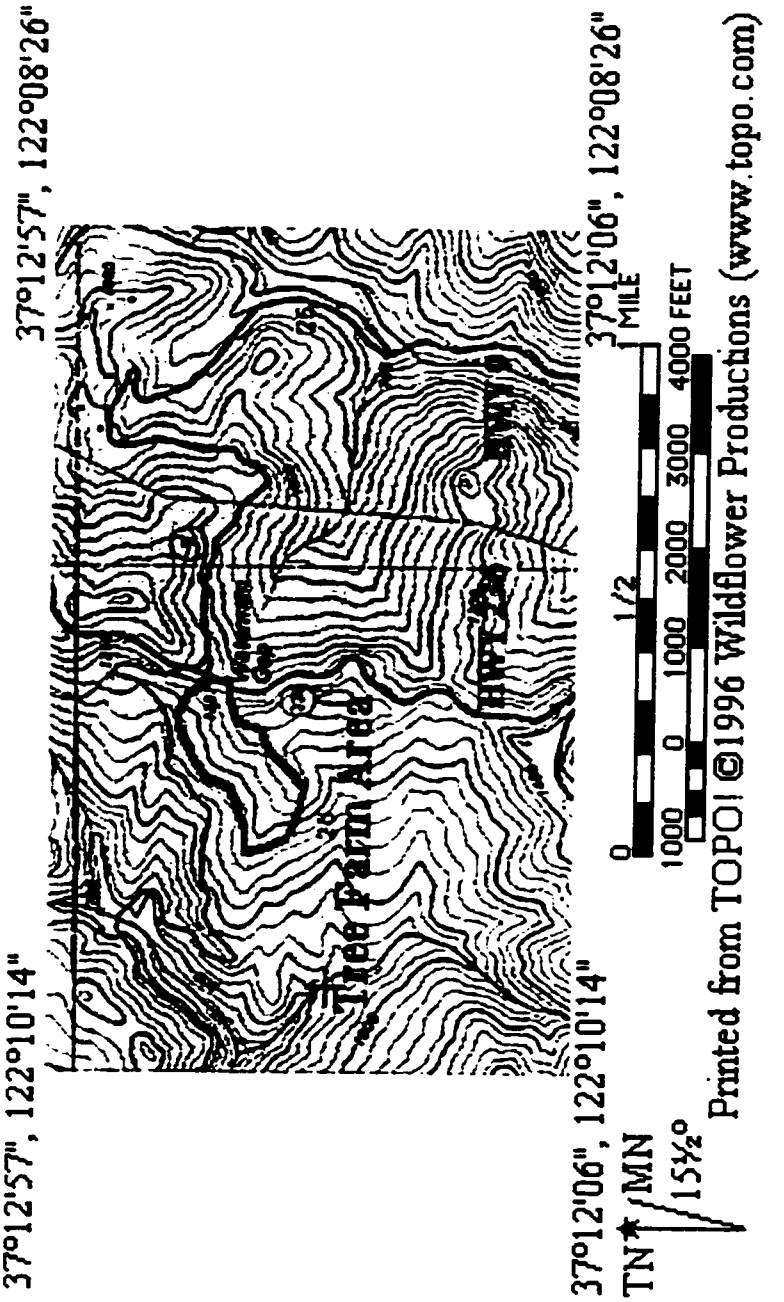

Figure 4.—Tree Farm Study Area

Finally, the soil types were generally similar. All consisted of sandy loam complexes on 30% to 75% slopes (Bowman and Estrada 1980). Specifically, the old growth area was a Lompico-Felton complex derived from sandstone, the second growth was Sur-Catelli complex also derived from sandstone, and the tree farm was composed of both of these, as was the majority of the region.

It is not known how similar the areas were with respect to fire and flood histories although all have been managed to suppress fire during the past century and none of the areas were in active floodplains.

Site Selection within Areas

Fifteen sites within each study area were randomly selected. In all cases, sites had to be out of sight of the trail, accessible on foot, and on generally west facing slopes. The second growth area had an additional site placed at a boundary between second and old growth. Site selection consisted of beginning at a starting point on the trail or road, traveling along the path a randomly generated distance from 100 feet to 300 feet (about 30 m to 90 m) and then locating the site at a randomly generated distance perpendicular to the road or trail ranging from 0 feet to 300 feet (about 0 m to 90 m).

Abiotic Measures

At each site, abiotic measurements consisting of soil moisture, soil temperature, litter depth, slope, aspect, and distance to nearest trail were taken in the first week of June 1997. Material removed for pitfall trap placement

was weighed with a Pelouze Model X-1 postage scale before and after sun drying for three days to determine the percent water by weight of each soil sample (Brower, Zar, and von Ende 1998). Some of the sites did not have soil per se at the measurement depth but rather had finely decomposed wood that probably has different water retention properties than mineral soil. Soil temperatures were recorded by a Taylor indoor/outdoor thermometer using the indoor thermometer for the surface temperature and the outdoor probe at a depth of 5 inches (13 cm) in the hole dug for the pitfall trap for temperature at depth. Litter depth was measured with a ruler inside each hole. A Suunto A1000 compass was used to measure the slope and aspect of each site The perpendicular distance from the nearest trail to each point was measured using a landscaper's style 100 foot measuring tape.

Pitfall Traps

In this study pitfall traps were used to measure the "active density" of litter arthropods (Topping and Sunderland, 1992). A trap consisted of a polystyrene beer cup 5 inches (13 cm) tall and 3.5 inches (8.5 cm) wide at the the mouth buried so that the lip was flush with the surface. A smaller salsa cup filled with water and a drop of dish soap was placed at the bottom of the beer cup. Water reduces the likelihood of differential attraction or repulsion of arthropods and is less toxic than the commonly used preservative ethylene glycol (Hurd and Fagan 1992). The soap broke the surface tension so that animals would sink and drown rather than escape. Then a funnel constructed from a frustrum shaped plastic coffee cup with the bottom removed was inserted. Above the trap, a drink lid container suspended by

bamboo shishkabob skewers kept debris from falling into the trap.

Topping and Sunderland cautioned that "unless the species under investigation have been carefully studied so that the factors which affect the catch are understood, pitfall traps can only be sensibly used for the production of qualitative data or to create a pitfall catch index to interpret ecological differences between sample areas" (1992, 490) This limitation is because pitfall traps directly measure activity rather than density and different species have varying probabilities of being trapped (Mciver, Moldendke, and Parsons 1992; Topping and Sunderland 1992). Researchers have assumed that these factors do not affect the detection of changes in species distributions along environmental gradients and that pitfall traps are a valid method for ecological distribution studies (Uetz 1977; Mciver, Moldendke, and Parsons 1992; Topping and Sunderland 1992).

Traps were set up and left open during June 1997 with a total of 1199 trap days, found by summing the number of days a trap was open across all traps. This study did not expect to catch, nor did it capture, any Federally or State listed endangered or threatened arthropods. The only listed arthropods in the Santa Cruz Mountains occur in Zayante sand hill habitat and not in redwood or mixed evergreen forest (Fish and Wildlife Service 1997). Traps were checked about once per week. Some were disturbed or destroyed by animals and had to be reset. Arthropods were preserved in 80% ethanol and identified at least to order, usually to family, and in the case of spiders to genus or species. Arthropod identification followed Borror, Triplehorn, and Johnson (1989) and spiders also followed Roth (1993) and Levi and Levi (1990), with personal assistance provided by spider taxonomists Darryl Ubick and Dr. Griswold of the California Academy of Sciences.

Web Counts

Web counts at each site supplemented pitfall trapping. Counts occurred around the point where the trap lay. The site was divided into quarters along the cardinal directions and each quarter was searched for 30 seconds for webs within a radius of 3 meters and below a height of 1.5 meters.

Webs were classified by structure into sheet, dome, orb, hammock, or other. Sheet webs are those built in leaf litter such as the funnel webs of agelenids. Dome webs are found in vegetation and are made by linyphiids. Orb webs are planar snares constructed in vegetation often by araneids. Hammock webs are sheets constructed in the furrows of tree bark. Webs as defined here are loosely related to taxonomy and more closely to guild.

Counts were conducted in the summer and fall following the pitfall trapping. The fall count occurred at all sites in a two week period while the summer count spanned several months. As web abundance appeared to vary strongly with time, the summer count may have been unduly influenced by the extensive sampling period. Therefore, only the fall count was used in the canonical correlation. However the fall count occurred several months after the pitfall trapping so the web counts and trap data are separated by time.

Vegetation

For each site the point-quarter method was used (Barbour, Burk, and Pitts 1980) to measure tree and herb cover, and the density, dominance, and frequency of overstory trees, understory trees (where appropriate), shrubs, logs, and snags (standing dead trees). Tree and herb cover were estimated on a

subjective scale from 0 (no cover) to five (complete cover) (Mciver, Moldendke, and Parsons 1992). Tree cover estimations were made by standing on the sample point and observing directly overhead while herb cover was estimated within a roughly ten foot radius circle around the sample point. After taking tree and herb cover estimates, the sample point was divided into four quarters along the cardinal directions and point to plant, log, or snag distances were measured in each quarter.

From this data, density, dominance, and frequency values were calculated. Density represents the number of individuals per area found by measuring the distance from the point to the individual in each quarter. The squared mean distance is then divided into the unit area (such as an acre or hectare) to give the density measure. To be included in the survey, individuals had to be within 100 feet of the sampling point.

Dominance for trees and snags was based on the basal area derived from the circumference at breast height (about 1.5 meters). Dominance for shrubs was based on a cross-sectional area obtained from the product of the height and width of the plant. Dominance for logs was determined by estimating the volume from the diameter and length and assuming a cylindrical form. Tapering logs had their diameter measured at a point estimated to approximate the equivalent volume of a cylinder of that diameter.

Frequency represents the number of sample points in which an individual appeared. Relative values of density, dominance, and frequency were calculated for each species in each area by dividing the measure for a species by the sum of the measures for all species and then multiplying by 100. These values can be thought of as answering the following questions about a

plant species: how many (density), how big (dominance), and how distributed (frequency). The sum of the relative values is refered to as the importance value of the species and is used to evaluate how influential a species may be in the local plant community (Brower, Zar, and von Ende 1998).

Multistemmed trees were counted as an individual with the basal area of each stem measured and summed for a total basal area. Occasionally, identifying individuals proved problematic particularly with redwoods who are prone to root or stump sprouting so that stems that do not appear connected above ground may be connected by a common root structure. To avoid this problem, one could simply measure to the nearest stem. However, redwoods often consist of a large main stem surround by smaller root sprouts so that only including the nearest stem would result in a gross underestimate of basal area especially in mature stands. More accurate determinations based on methods such as excavating root structures, tracing injected radioisotopes or other chemicals, or comparison of DNA "fingerprints", were all too disruptive, too toxic, and/or too expensive. In this study, it was estimated which stems belonged to an individual. While this introduced a layer of arbitrariness, it was kept consistent by evert determination being made by the same individual.

Repeated measures of tree measurements indicated a discrepancy with a mean of approximately two stems in regards to counting stems that belonged to a single individual. Stem counting error contributed to the total error in estimation of basal area ranging from 2% to 20% with a median error of 2%. Another source of error in basal area estimation stemmed from measuring the circumference of trunks. The mean error in circumference

measurements was 1.3 inches (3.3 cm) overall and seemed to be about 1 inch (2.54 cm) for smaller trunks (under 100 inches or 254 cm in circumference or about 30 inches or 76 cm in diameter) and about 2 inches (5.08 cm) for larger trunks (over 100 inches or 254 cm). This translates to a basal area error of about 4% for a 16 inch (41 cm) diameter trunk and less than 1% for a 64 inch (163 cm) diameter trunk from circumference measurement error.

Error in density measurements came from error in measurement of the distance from the center point to the individual. There did not appear to be a pattern of magnitude or direction of error related to measured distance, so repeated measures for all vegetation types were used to calculate the error. The mean of the absolute values of the errors in distance measurement was 7.7 inches or 0.19 meters. This translates to a density error of about 3.7% of the mean density or about 1.5 trees per acre or 3.7 trees per hectare. The degree of error in estimation resulting from measurement error and study design appeared acceptable for the purposes of this study.

Statistical Analysis

Vegetation data were converted into importance values based on density, dominance (basal area), and frequency for each of the three areas for comparative purposes. Species-sample curves based on the spider catch were constructed to assess whether adequate sampling had occurred. Then arthropod catches and site characteristics including number of logging events were subjected to a canonical correlation analysis using SPSS (Norusis 1994).

Canonical correlation is the most general of multivariate tests (Tabachnick and Fidell 1989). Two sets of variables are related to each other

rather than two variables as in a bivariate correlation or ANOVA. Often each set consists of a set of measures with a central concept such as a set that contains the abundances of three different spider guilds or a set containing several measures of habitat structure. These sets may or may not represent independent and dependent variables. The analysis seeks linear combinations that produce predicted values for each set with the maximum correlation with predicted values for the other set. For each combination, each set will have a subset of variables that relate strongly to the other set and are then interpreted. Usually only the first or second combinations are significant if any. Despite the difficulty in interpreting results, canonical correlation can allow the analysis of relations between multidimensional concepts.

RESULTS

Arthropod Catch

With a total of 1199 trapping days for all sites combined, 1742 arthropods were caught for a capture rate of about 1.45 animals per day. Of these, 248 were beetles with 152 of these being carabids, 288 were ants, 295 were orthopterans with all being camel crickets (Gryllacrididae, Rhaphidophorinae), 471 were bristletails (order Microcoryphia), 132 were dipterans, and 129 were spiders. Table 1 shows the species catch of spiders per study area. Of these, 44 were diurnal hunters 21 of whom were *Xysticus* sp. (Thomisidae), 38 were nocturnal hunters of whom 35 were *Zelotes* sp. (Gnaphosidae), and 47 were web builders of whom 16 were *Ceratinops inflata* (Erigonidae).

A total of 23 spider species were trapped, 33 species of all arachnids, and at least 81 species of arthropods overall although most arthropod groups were identified only to order and in some cases family so that the total number of arthropod species is higher.

The fall web count included 526 webs of which one was a dome web, 295 were sheet webs, 201 were hammock webs, 27 were orb webs, and two were of other types.

Table 1.—Pitfall Catches of Spiders by Species in each Study Area

Family	Genus	Guild	Old Growth	Second Growth	Tree Farm	Total
Agelenidae (Dictynidae)	*Blabomma* sp. 1	W	6	3	1	10
Agelenidae (Dictynidae)	*Blabomma* sp. 2	W			1	1
Agelenidae	*Cybaeus* sp.	W		1		1
Agelenidae	*Ethobuella* sp.	W	1			1
Agelenidae	*Novalena* sp.	W		2	1	3
Amourobiidae	*Pimus* sp.	W	2	2	4	8
Clubionidae		D		1		1
Clubionidae (Corrinnidae)	*Castianeira thalia*	D		1		1
Cyrtauchenidae	*Promyrmekiaphila* sp.	D	1			1
Erigonidae	*Ceratinops inflata*	W	7	7	2	16
Gnaphosidae	*Drassylus* sp.	N	2	1		3
Gnaphosidae	*Zelotes* sp.	N	20	10	5	35
Hahniidae	*Calymmaria* sp. 1	W	2		1	3
Hahniidae	*Calymmaria* sp. 2	W	1			1
Liocranidae	*Phrurotimpus* sp.	D	5			5
Lycosidae	*Alopecosa* sp.	D	2	4	3	9
Lynyphiidae	*Lepthyphantes* sp.	W	2			2
Lynyphiidae	*Pityohypanthes* sp.	W	1			1
Salticidae	*Sitticus* sp.	D		1		1
Salticidae	*Tylogonus morosus*	D	1	2	1	4
Segestridae	*Segestria* sp.	D			1	1
Thomisidae	*Xysticus* sp.	D	11	5	4	20
Thomisidae	*Ozyptila* sp.	D	1			1
Total			63	41	25	129

Note: D = diurnal hunters, N = nocturnal hunters, W = web builders

Spider Species-Sample Curve

To assess whether a sampling effort is sufficient to describe a community, one can plot the cumulative number of new species encountered with the inclusion of each additional sample site. Such a plot is termed a species-sample curve (Brower, Zar, and von Ende 1998). If the plot levels off, that is, if considering additional sites adds few or no new species, then we can be confident that we have observed at least the most common members of the community that can be sampled with the methods used. The rate at which new species are added and where the curve levels off are related in part to the diversity of the community as well as to the particulars of the sampling method and organisms. A rapid increase would suggest the community is dominated by few common species whereas a slower increase would suggest a more even distribution of abundance or more rare species.

For this study, sample-species curves were plotted for spiders for all sites combined and for each sample area separately. Sites were randomly drawn and the number of new species encountered recorded and are shown in Figure 5. The combined plot shows a leveling beginning at 18 species and slowly increasing to 23 species after 23 sample sites were included or about 1 new species for every five sites. This suggests that many of the most common species may have been included in this study.

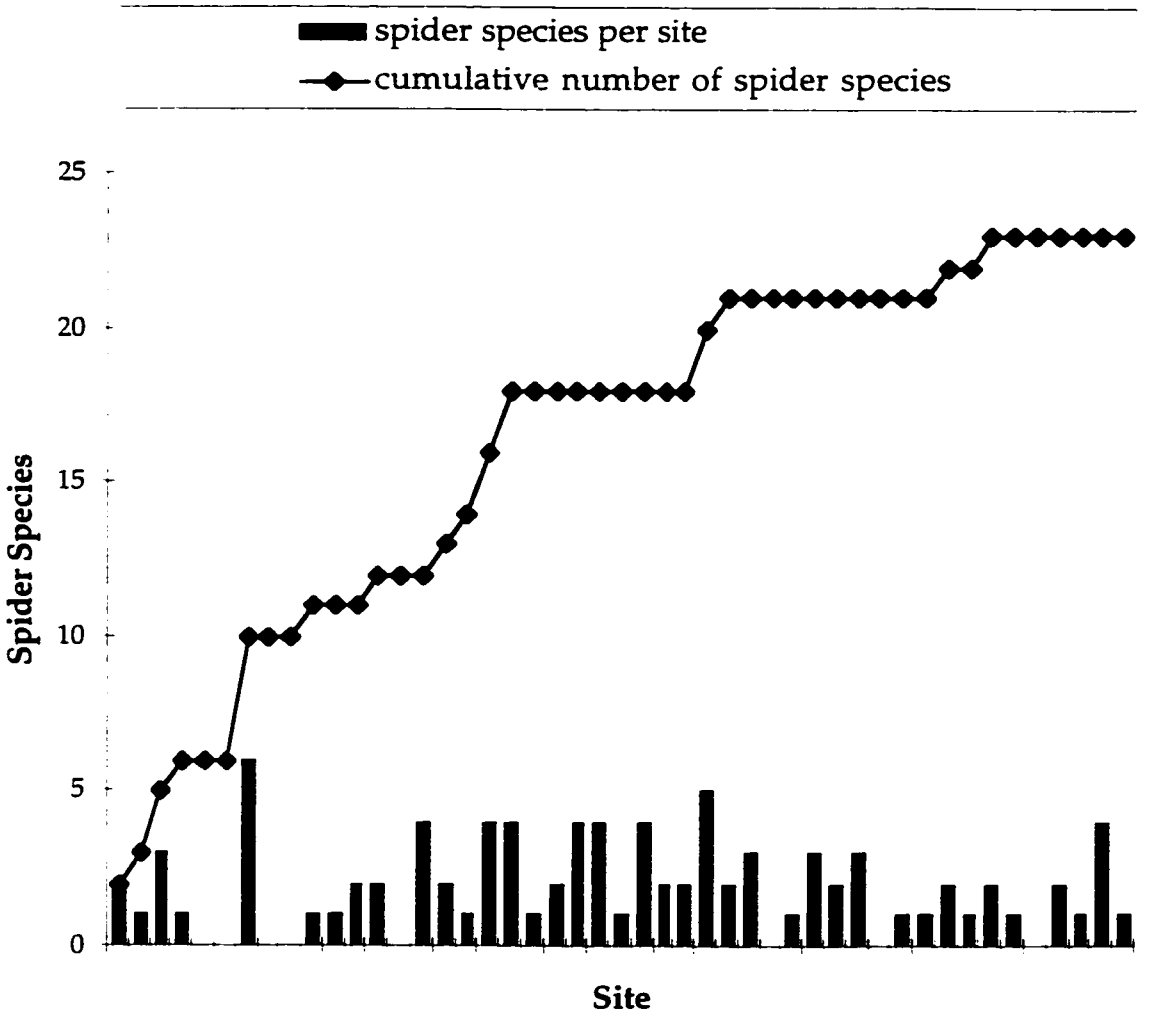

Figure 5.—Species-sample Curve for All Sites

Looking at the curves by area, the Old Growth area begins to level at 11 species after 5 sites and increases to 14 species over the last 10 sites or about one new species for every three sites (see Figure 6). The Second Growth area levels at 16 species (see Figure 7). The Tree Farm may be leveling at 12 species although a few more species probably would be encountered with further sampling (see Figure 8).

The Second Growth area levels at the highest number of species while the Old Growth contains the highest rate of new species accumulation. Fifteen sites per area appears adequate. However, twenty or more sites for perhaps a two month period would probably catch all the common species and at least some if not many of the rare species. This would allow more variables to be used in a canonical analysis and would tolerate the destruction of some traps due to animals or inclement weather.

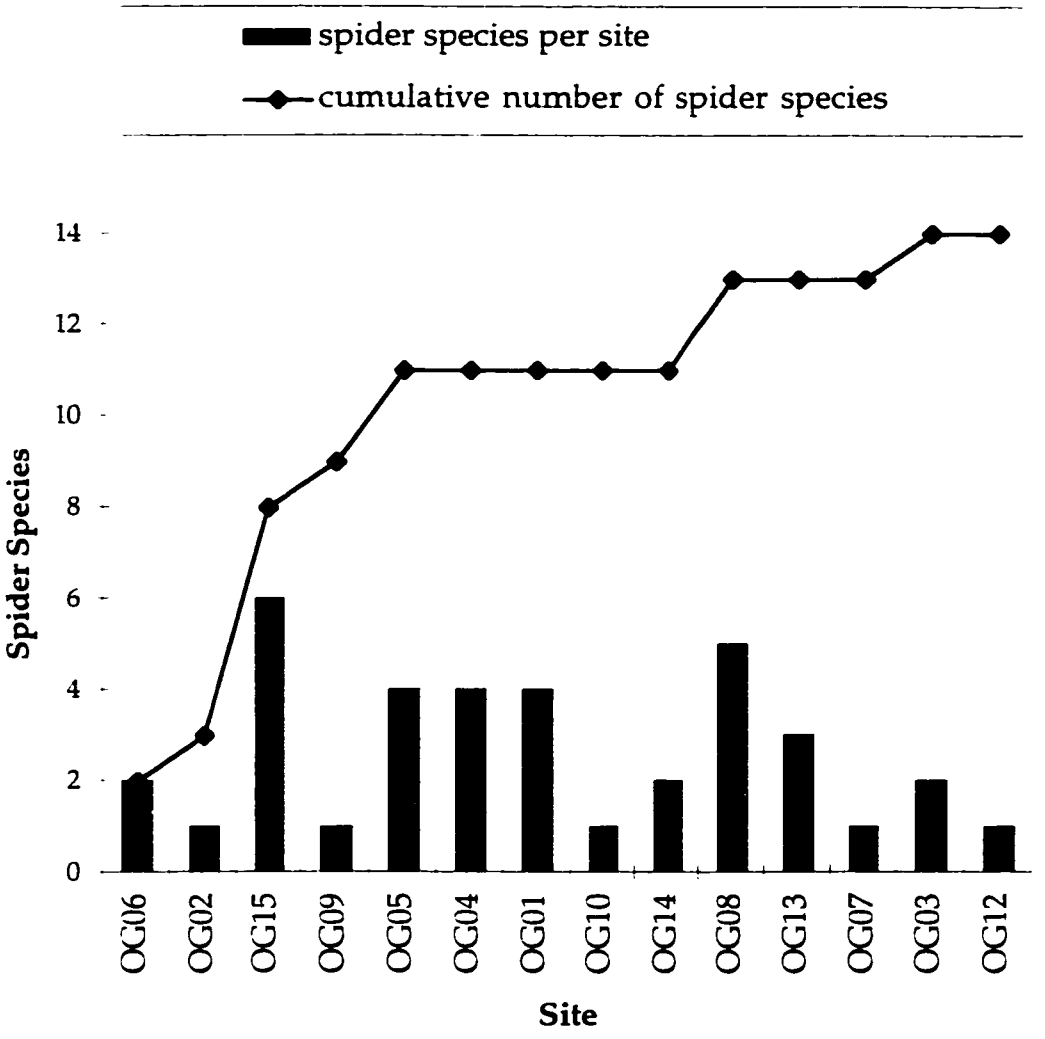

Figure 6.—Species-sample Curve for Old Growth Sites

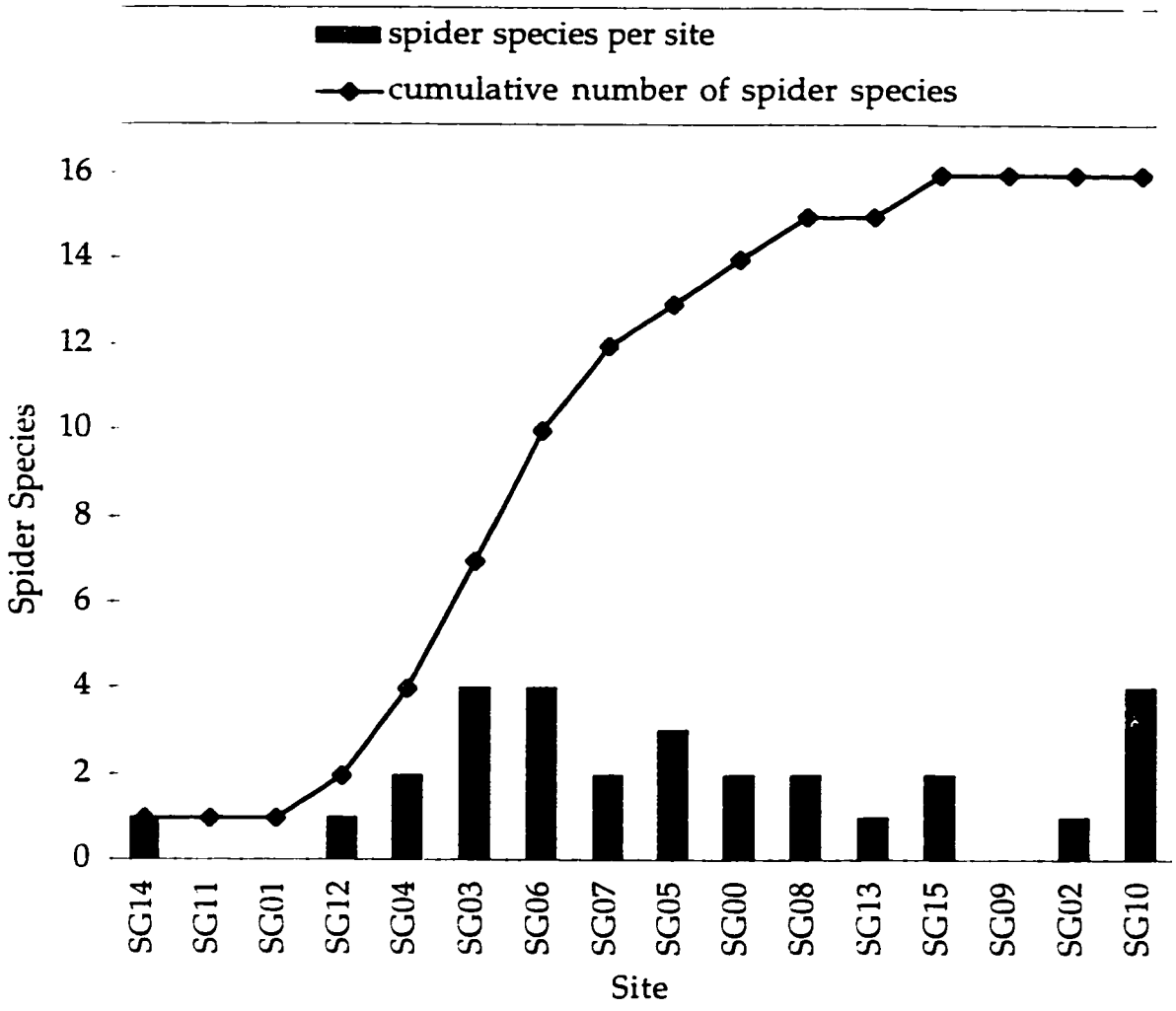

Figure 7.—Species-sample Curve for Second Growth Sites

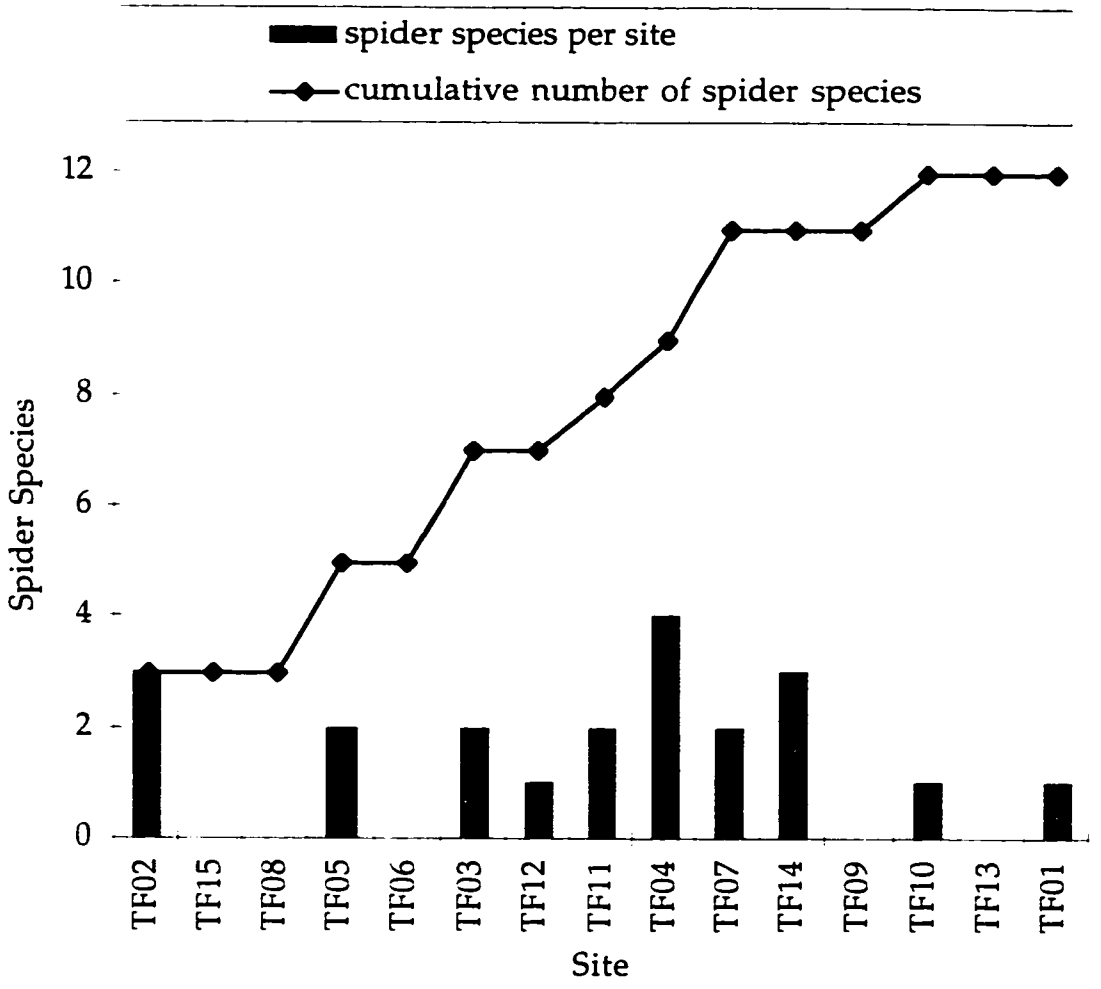

Figure 8.—Species-sample Curve for Tree Farm Sites

Vegetation Analysis by Area

Old Growth

Old growth overstory was dominated by redwoods and Douglas-fir. Oaks (*Quercus* sp.) and madrones occasionally formed overstory in gaps caused by tree falls (see Figure 9 and Table 2). The oaks observed appeared to have field characteristics most similar to those for interior live oaks (*Quercus wislizenii*), but because of the variability in these characteristics and hybridization possibilities, these simply will be labeled oaks (*Quercus* sp.).

Understory were mostly tanoaks (*Lithocarpus densiflora*). Other understory trees were madrones (*Arbutus menziesii*), oaks (*Quercus* sp.), Douglas-fir, and redwoods. Shrubs were generally young tanoaks and to a lesser extent oaks, huckleberry (*Vaccinium ovatum*), sword ferns (*Polystichum munitum*), and young Douglas-fir. Snags were mostly large Douglas-fir and madrone with some oaks and tanoaks.

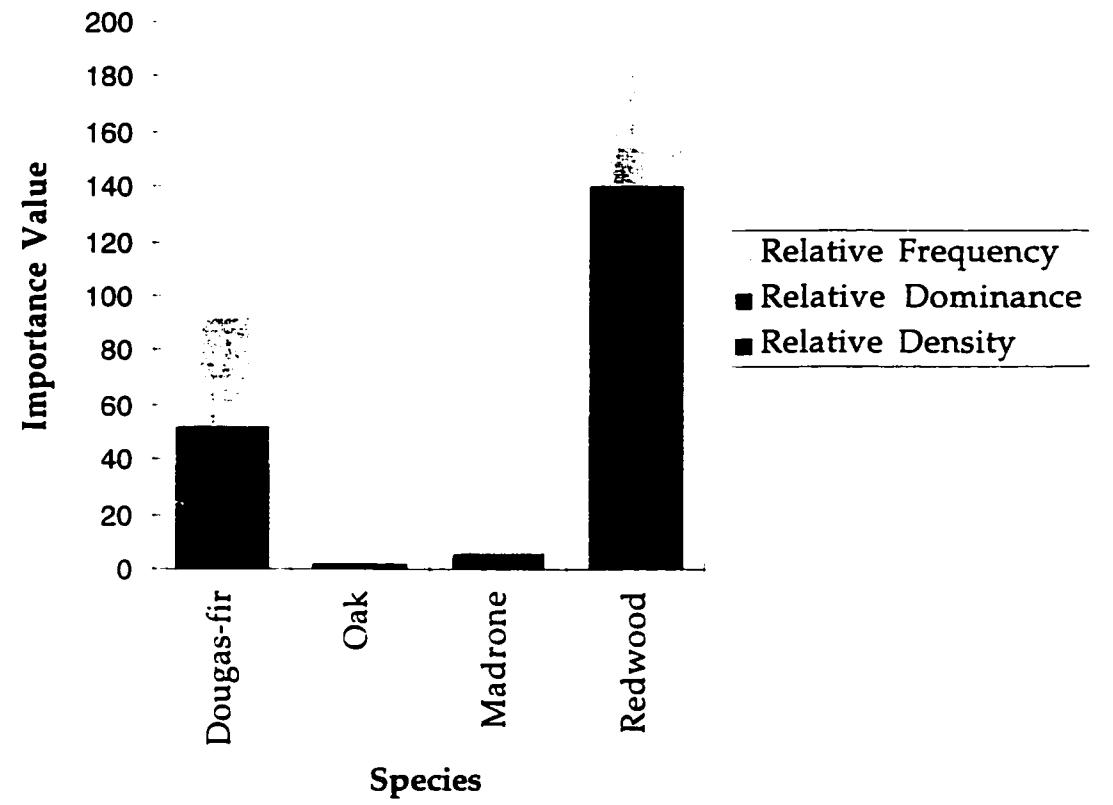

Figure 9.—Importance Values of Overstory Trees in the Old Growth Study Area

Table 2. — Old Growth Vegetation

	Number of Individuals	Density (trees/ha±1 s.e.)	Dominance (m^2/ha±1 s.e.)	Frequency	Importance Value
Snags					
Douglas-fir	5	17 ± 2.2	6.4 ± 0.84	3	125
Madrone	5	17 ± 2.2	0.94 ± 0.12	4	79
Oak	2	6.6 ± 0.84	1.6 ± 0.21	2	47
Tanoak	3	10 ± 1.3	1.1 ± 0.64	2	49
n	15				
Overstory					
Douglas-fir	24	37 ± 3.2	55 ± 4.7	10	104
Madrone	3	4.7 ± 0.40	1.7 ± 0.15	2	14
Oak	1	1.6 ± 0.13	2.6 ± 0.23	1	7
Redwood	36	56 ± 5.0	150 ± 13	12	175
n	64				
Understory					
Douglas-fir	8	32 ± 3.0	0.77 ± 0.80	4	35
Madrone	9	36 ± 3.4	2.5 ± 0.24	5	57
Oak	5	20 ± 1.9	1.5 ± 0.14	4	37
Redwood	3	12 ± 1.2	0.38 ± 0.036	3	20
Tanoak	38	150 ± 15	5.2 ± 0.5	11	152
n	63				
Shrubs					
Douglas-fir	1	15 ± 1.9	0.64 ± 0.10	1	6
Huckleberry	1	15 ± 1.9	23 ± 3.6	1	10
Oak	16	240 ± 30	110 ± 16	6	71
Sword Fern	1	15 ± 1.9	0.88 ± 0.14	1	6
Tanoak	40	610 ± 75	520 ± 80	13	207
n	59				

Second Growth

Second growth overstory was dominated by redwoods. Douglas-fir and tanoaks also often formed the overstory (see Figure 10 and Table 3). Oaks and madrones rarely formed overstory and then only in gaps caused by tree falls. Understory trees were mostly tanoaks while other understory species included Douglas-fir, madrones, redwoods, and oaks. Shrubs were mostly tanoak saplings in addition to huckleberry shrubs, redwood saplings, oaks, a rush (*Juncus* sp.), a *Ceanothus* sp., and a madrone sapling. Snags were mostly madrones and tanoaks, along with a single redwood.

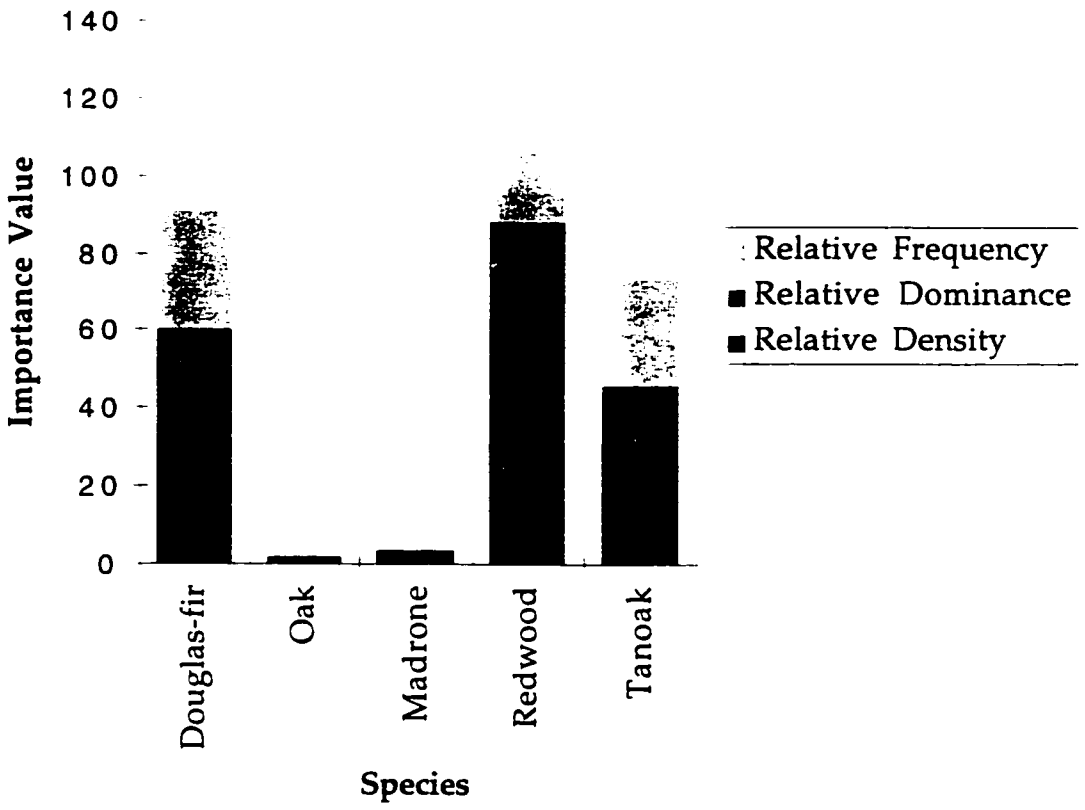

Figure 10.—Importance Values of Overstory Trees in the Second Growth Study Area

Table 3. — Second Growth Vegetation

	Number of Individuals	Density (trees/ha±1 s.e.)	Dominance (m^2/ha±1 s.e.)	Frequency	Importance Value
Snags					
Madrone	3	100 ± 20	7.6 ± 1.5	3	132
Redwood	1	34 ± 6.8	5.6 ± 1.1	1	60
Tanoak	3	100 ± 20	6.3 ± 1.3	2	110
n	7				
Overstory					
Douglas-fir	21	130 ± 7.0	39 ± 2.0	10	91
Madrone	2	12 ± 0.65	0.72 ± 0.038	2	10
Oak	1	6.2 ± 0.33	0.61 ± 0.032	1	5
Redwood	20	124 ± 6.5	79 ± 4.2	11	121
Tanoak	20	124 ± 6.5	20 ± 1.0	9	73
n	63				
Understory					
Douglas-fir	10	160 ± 16	2.4 ± 0.25	9	64
Madrone	6	94 ± 10	1.9 ± 0.19	5	40
Oak	4	63 ± 6.0	1.2 ± 0.12	3	25
Redwood	3	47 ± 4.7	1.7 ± 0.17	3	27
Tanoak	30	470 ± 47	6.2 ± 0.60	14	144
n	53				
Shrubs					
Ceanothus	1	29 ± 2.7	10 ± 1.5	1	6
Douglas-fir	5	140 ± 14	64 ± 10	3	23
Huckleberry	7	200 ± 19	160 ± 24	4	35
Madrone	1	29 ± 2.7	5.0 ± 0.75	1	6
Oak	7	200 ± 19	45 ± 6.5	3	25
Redwood	5	140 ± 14	210 ± 31	3	31
Rush	1	29 ± 2.7	16 ± 2.4	1	6
Tanoak	33	200 ± 19	1300 ± 190	12	170
n	60				

Tree Farm

Tree farm overstory was dominated by redwoods (see Figure 11 and Table 4). Other trees included tanoaks, oaks, Douglas-fir, and a *Ceanothus* sp. Understory was largely nonexistent with only four individuals in three sites. These were two *Ceanothus* sp., a tanoak, and an oak. Shrubs were often sword fern, along with tanoak saplings, huckleberry, oaks, *Ceanothus* sp., redwood saplings, a Douglas-fir sapling, an iris, and a madrone sapling. Only one snag was found, which was an oak.

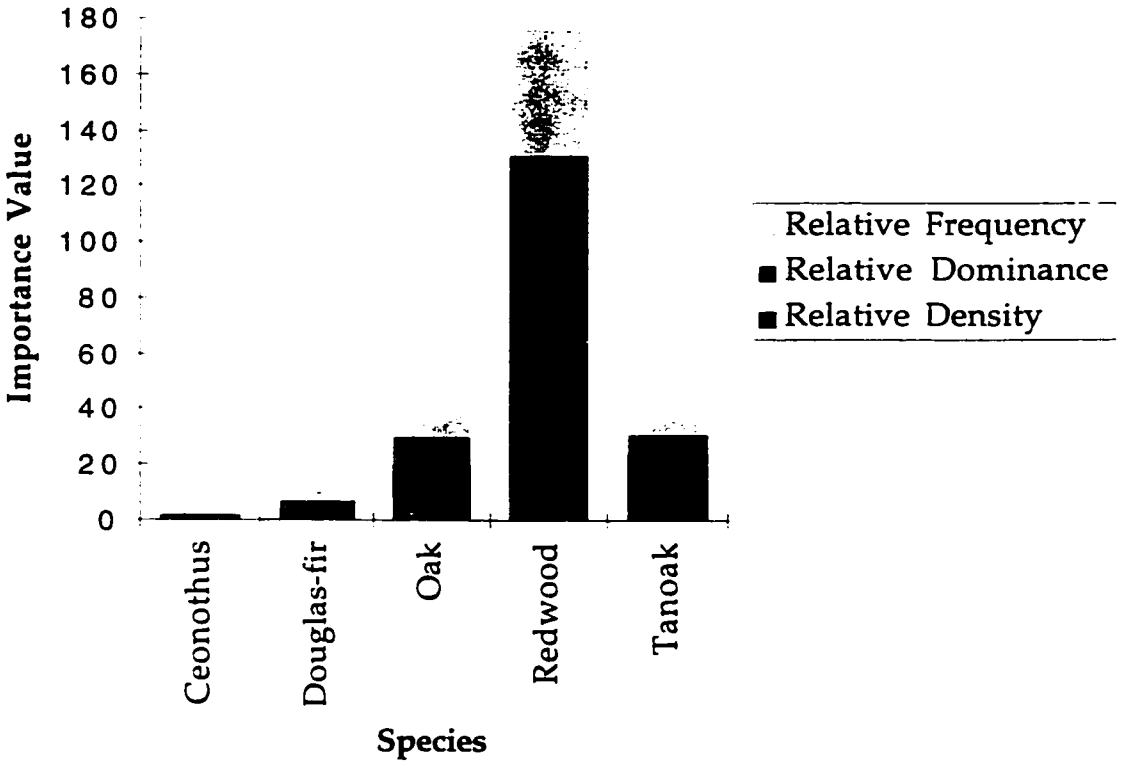

Figure 11.—Importance Values for Overstory Trees in the Tree Farm Study Area

Table 4. — Tree Farm Vegetation

	Number of Individuals	Density (trees/ha±1 s.e.)	Dominance (m^2/ha±1 s.e.)	Frequency	Importance Value
Snags					
Oak	1	N/A	N/A	1	N/A
Overstory					
Ceanothus	1	6.4 ± 0.60	0.074 ± 0.0070	1	5
Douglas-fir	2	13 ± 1.2	5.6 ± 0.50	1	10
Oak	12	76 ± 7.0	15 ± 1.4	6	50
Redwood	30	190 ± 17	130 ± 12	13	176
Tanoak	14	89 ± 8.0	11 ± 1.0	8	58
n	64				
Understory					
Ceanothus	2	560 ± 120	4.0 ± 0.86	1	127
Oak	1	280 ± 61	0.70 ± 0.15	1	66
Tanoak	1	280 ± 61	4.5 ± 0.97	1	107
n	4				
Shrubs					
Ceanothus	2	73 ± 8.9	50 ± 8.9	2	16
Chain Fern	2	73 ± 8.9	19 ± 3.5	2	14
Douglas-fir	1	37 ± 4.3	36 ± 6.4	1	9
Huckleberry	3	110 ± 13	280 ± 49	3	44
Iris	1	37 ± 4.3	9.0 ± 1.6	1	7
Madrone	1	37 ±4.3	6.2 ± 1.1	1	6
Oak	4	150 ± 17	130 ± 23	3	32
Redwood	2	73 ± 8.9	37 ± 6.4	2	15
Sword Fern	16	580 ± 69	270 ± 48	11	103
Tanoak	6	220 ± 26	240 ± 43	5	54
n	38				

Logs

As presented in Table 5, the old growth area seemed to have a few large logs in virtually all sites and the second growth area had many small logs in most sites while the tree farm area had many logs in just over half the sites and none in just under half the sites.

Table 5. — Log Density and Abundance in All Areas

Site	n	Density (logs/ha±1 s.e.)	Dominance (m^3/ha±1 s.e.)	Frequency (%)
Old Growth	61	130 ± 17	$4.9 \times 10^4 \pm 7.0 \times 10^3$	95
Second Growth	57	410 ± 44	$2.6 \times 10^4 \pm 3.9 \times 10^3$	89
Tree Farm	33	290 ± 35	$5.8 \times 10^4 \pm 6.9 \times 10^3$	55

Comparison of Vegetative Heterogeneity

The old growth area had the most vegetative heterogeneity with three vegetation layers, a snag component, and extensive downed wood. The tree farm had the least heterogeneity with only the overstory layer being consistently present, a moderately consistent shrub layer, essentially no understory layer, no snag component, and downed logs absent in almost half the sites. The second growth appeared structurally intermediate with three distinct vegetative layers, some snags, and many logs in most sites. The overstory trees in the second growth were much smaller in size than the old

growth trees and showed a less clear dominance of redwoods.

These differences in habitat structure, presumably due to human management, are important to consider as spiders and other arthropods have been found to react to habitat differences, individually through behavior, and collectively through the assembly of communities (Robinson 1981; Uetz 1979; Uetz 1990; Gunnarsson 1990; Sundberg and Gunnarsson 1994, Pettersson *et al.* 1995; Økland 1996).

Canonical Correlation Analysis

Canonical correlations were performed between sets of abundance and diversity measures and sets of site characteristics using SPSS Manova (Norusis 1994). Sets used as dependent variables are shown in Table 6. Abundances were natural log transformed, ln(x+1), to improve linearity and normality for the analysis. Species richness consisted of the number of species at a site and evenness was calculated using the Shannon-Wiener index:

$$E = H'/Hmax = (-\Sigma p \ln p)/\ln S,$$

where p is the relative abundance of a species and S is the total number of species (Margurran 1988). While species richness shows how many different species are present, evenness describes whether one or a few species is numerically dominant or if all species are present in more or less equal numbers. An evenness measure of one means that all species are present in exactly equal abundances with the index decreasing from one in proportion to the numeric dominance of the most abundant species.

Table. 6 — Definitions and descriptions of dependent variable sets used in the canonical correlation analysis.

Set Name	Variables in Set	Set Description
Spider Diversity	Abundance* Richness Evenness	Spider community diversity measured several ways.
Spider Guild	Nocturnal hunters Diurnal hunters Web builders	Spider community defined by the natural log of abundances in each hunting style guild.
Web Type	Dome Hammock Orb Sheet	Spider community defined by the natural log of abundances of observed web architectures.
Arthropod Diversity	Abundance* Richness Evenness	Arthropod diversity measured several ways.
Arthropod Guild	Detritivores Herbivores Omnivores Predators	Arthropod community defined by the natural log of abundances in each feeding guild.

* Log transformed for analysis

Sets used as independent variables are described in Table 7. The global site set included herb and tree cover estimates, slope, litter depth, number of logging events, and the natural log of percent soil moisture. This set described a site by using measures and estimates obtainable with less effort than more intensive techniques.

The vegetation density site set was composed of the number of logging events and the natural log transforms of mean overstory, understory, shrub, and log distances, and soil moisture. This second site set represented labor-intensive measures of vegetation density, moisture, and logging history.

Table. 7 — Definitions and descriptions of independent variable sets used in the canonical correlation analysis.

Set Name	Variables in Set	Set Description
Global Site Set	Herb Cover Litter Depth Logging Events Slope Soil Moisture Tree Cover	Overall site characteristics derived from time efficient measures and estimates.
Vegetation Density	Log Density Logging Events Overstory Density Shrub Density Soil Moisture Understory Density	Site structural complexity based on time intensive measures such as point to plant distances.

All data were checked for normality, linearity, homoscedasticity. While variables need not meet these conditions, canonical analysis is improved if they are (Tabachnick and Fidell 1989). As mentioned, some variables were natural log transformed to improve normality and linearity. Many variables showed heteroscedasticity, which may have reduced the quality of the analysis.

Data were also checked for outliers. Two observations (sites OG11 and OG11') were observed to be outliers probably due to their shortened trapping times. This was the result of OG11 being destroyed and OG11' set up as a replacement. Combining the sites was considered unacceptable as they were far enough apart for the site characteristics to be different and so they were omitted from the canonical analyses. This left an N = 45. Finally, data met assumptions for within-set multicollinearity.

Spider Diversity Sets

As shown in Table 8, the spider diversity set with the global site set gave one significant canonical correlation ($F(18,102.31) = 2.29$, $p = 0.005$). The spider diversity set showed a within-set variance accounted for by the canonical variates of 43% and a redundancy of 22% while the global site set's within variance accounted for was 29% and its redundancy was 15%. Abundance and species richness increased with increasing herb cover and decreasing logging, tree cover, litter depth, and soil moisture. The number of individuals and species of litter spiders was higher in unlogged, drier, open but herbaceous sites.

The spider diversity set with the vegetation density set gave one significant canonical correlation ($F(18,102.31) = 1.75$, $p = 0.042$). The spider

diversity set showed a within-set variance accounted for by the canonical variates of 74% and a redundancy of 32% while the vegetation density set's within variance accounted for was 15% with a redundancy of 6%. Abundance, species richness, and evenness decreased with increased logging and moisture and decreasing overstory distance. Wet, logged, dense sites had fewer individuals and species of spiders and were more likely to be dominated by a few species.

Table 8.—Canonical coefficients and loadings of variables larger than ±0.3 in the spider diversity set and site sets

Global Site Set			
Canonical Correlation		0.725	
Squared Canonical Correlation		0.526	
p-value		0.005	
Spider Diversity		Site Characters	
Abundance	0.819	Herb Cover	0.794
Richness	0.744	Times Logged	-0.590
		Tree Cover	-0.535
		Litter Depth	-0.525
		Soil Moisture	-0.442
Vegetation Density Set			
Canonical Correlation		0.655	
Squared Canonical Correlation		0.429	
p-value		0.042	
Spider Diversity		Site Characters	
Abundance	-0.972	Overstory Distance	-0.592
Richness	-0.934	Times Logged	0.584
Evenness	-0.629	Soil Moisture	0.406

Spider Guild Sets

The relative abundance of nocturnal spiders increased as we moved from more logged to unlogged areas while web builders showed a relative decrease and diurnal hunters showed a modest relative decrease (see Figure 12). The canonical correlation of the spider guild set with the global site set was significant ($F(18,102.31) = 1.92$, $p = 0.022$) as shown in Table 9. The spider guild set showed a within-set variance accounted for by the canonical variates of 42% and a redundancy of 20% while the global site set's within variance accounted for was 26% with a redundancy of 13%. Nocturnal and diurnal spider catches decreased with decreasing herb cover and increasing tree cover, logging, litter depth and soil moisture. Wet, logged sites with high tree cover and deep litter had fewer hunting spiders caught, especially for the nocturnal spiders.

The vegetation density set gave one significant canonical correlation ($F(18,102.31) = 1.75$, $p = 0.042$). The spider guild set showed a within-set variance accounted for by the canonical variates of 41% and a redundancy of 19% while the vegetation density set's within variance accounted for was 10% with a redundancy of 5%. Diurnal, web, and nocturnal spider catches decreased with increased logging and decreasing overstory distance. Logged, dense sites had lower catches of all guilds but particularly of diurnal hunters.

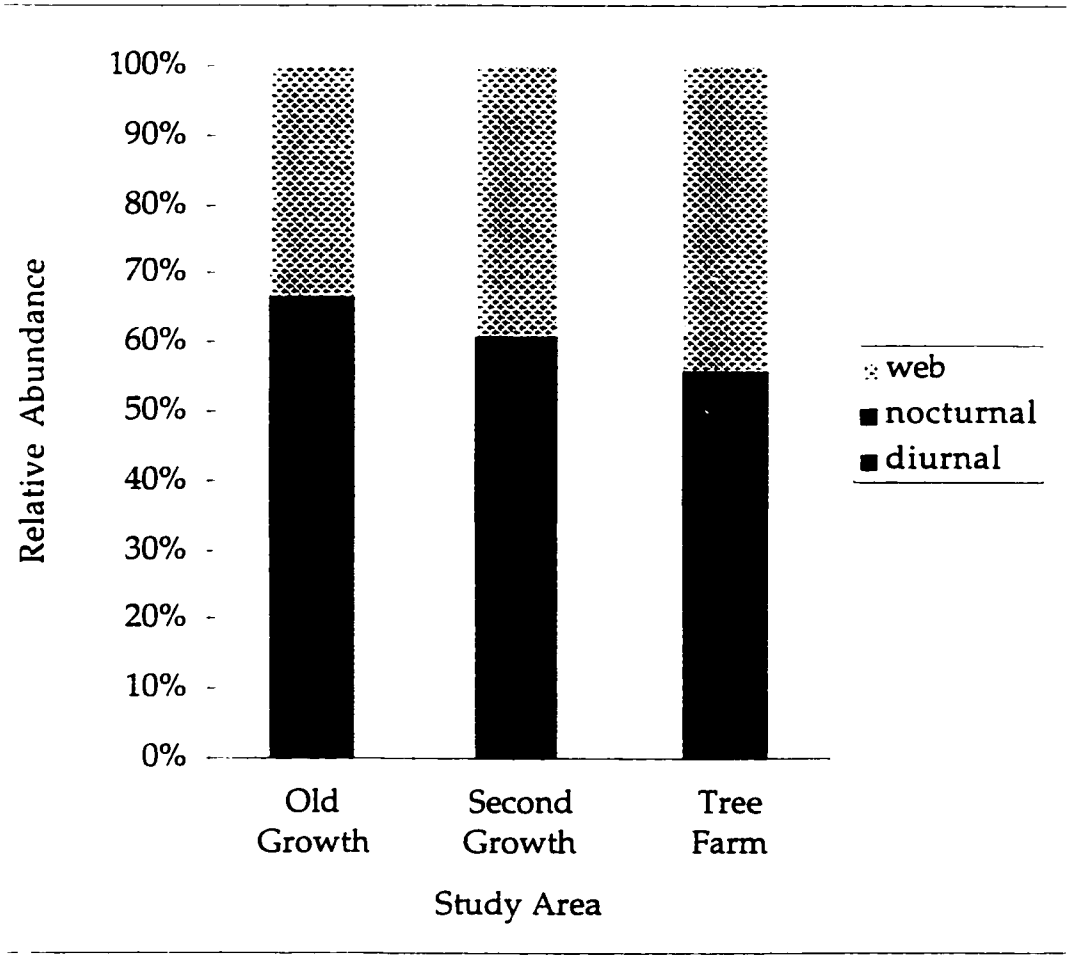

Figure 12.—Relative Abundances of Litter Spiders by Guild Caught in Pitfall Traps in each Study Area.

Table 9.—Canonical coefficients and loadings of variables larger than ±0.3 in the spider guild set and site sets

Global Site Set			
Canonical Correlation		0.698	
Squared Canonical Correlation		0.487	
p-value		0.002	
Spider Guild		Site Characters	
Nocturnal	-0.961	Herb Cover	-0.925
Diurnal	-0.527	Tree Cover	0.576
		Times Logged	0.376
		Litter Depth	0.337
		Soil Moisture	0.336
Vegetation Density Set			
Canonical Correlation		0.684	
Squared Canonical Correlation		0.468	
p-value		0.029	
Spider Guild		Site Characters	
Diurnal	-0.863	Overstory Distance	-0.925
Web	-0.507	Times Logged	0.576
Nocturnal	-0.473		

Spider Web Sets

The spider web set with the global site set gave one suggestive canonical correlation ($F(18,102.31) = 1.63$, $p = 0.055$) as seen in Table 10. The spider web set showed a within-set variance accounted for by the canonical variates of 46% and a redundancy of 14% while the global site set's within variance accounted for was 14% and a redundancy of 5%. It is suggested that sheet, hammock, and dome webs decreased with decreasing tree cover and litter depth and increasing herb cover and slope. These webs, especially sheet webs, were less frequent in open, steeper, herbaceous sites with thin litter layers. The spider web set with the vegetation density set gave no significant correlations.

Table 10.—Canonical coefficients and loadings of variables larger than ±0.3 in the spider web set and site sets

		Global Site Set	
Canonical Correlation		0.548	
Squared Canonical Correlation		0.301	
p-value		0.055	
Spider Webs		Site Characters	
Sheet	-0.951	Tree Cover	-0.796
Hammock	-0.572	Herb Cover	0.594
Dome	-0.367	Litter Depth	-0.584
		Slope	0.302

Arthropod Diversity Sets

The arthropod diversity set with the global site set gave two significant canonical correlations shown in Table 11. With all three canonical correlations included we find $F(18,102.31) = 3.84$, $p < 0.001$ and with the first removed we have $F(10,74) = 2.20$, $p = .026$. The arthropod diversity set showed a within-set variance accounted for by the first set of canonical variates of 54% and a redundancy of 33% while the global site set's within variance accounted for by the first canonical variate was 23% and a redundancy of 14%. The arthropod diversity set showed a within-set variance accounted for by the second set of canonical variates of 36% and a redundancy of 10% while the global site set's within variance accounted for by the second canonical variate was 25% and a redundancy of 7%. Arthropod abundance and species richness decreased with an increase in number of logging events and soil moisture and a decrease in herb cover. Abundance and richness also decreased with increasing understory and shrub distance and decreasing overstory distance. Evenness decreased with increases in logging events and herb cover and decreases in tree cover, litter depth, and slope.

The arthropod diversity set with the vegetation density set gave one significant canonical correlation ($F(18,102.31) = 3.42$, $p < 0.001$). The arthropod diversity set showed a within-set variance accounted for by the canonical variates of 46% and a redundancy of 28% while the vegetation density set's within variance accounted for was 24% and a redundancy of 14%. Richness and abundance increased with decreasing number of times logged, soil moisture, understory distance, shrub distance, and increasing overstory distance. Drier, unlogged sites with shrub and understory layers and widely spaced overstory trees had more litter arthropods and more species of litter arthropods.

Table 11.—Canonical coefficients and loadings of variables larger than ±0.4 in the arthropod diversity set and site sets

Global Site Set			
First Canonical Correlation	0.781		
Squared Canonical Correlation	0.609		
p-value	< 0.001		
Arthropod Diversity		Site Characters	
Richness	-0.960	Times Logged	0.684
Abundance	-0.814	Herb Cover	-0.656
		Soil Moisture	0.636
Second Canonical Correlation	0.519		
Squared Canonical Correlation	0.269		
p-value	0.026		
Arthropod Diversity		Site Characters	
Evenness	-0.937	Tree Cover	-0.669
		Times Logged	0.597
		Herb Cover	0.560
		Litter Depth	-0.478
Vegetation Density Set			
Canonical Correlation	0.773		
Squared Canonical Correlation	0.598		
p-value	< 0.001		
Arthropod Diversity		Site Characters	
Richness	0.946	Times Logged	-0.792
Abundance	0.701	Soil Moisture	-0.615
		Understory Distance	-0.431
		Shrub Distance	-0.349
		Overstory Distance	0.337

Arthropod Guild Sets

Total pitfall catches by area are shown in Table 12. Two sites, one in old growth area and one in the tree farm area had Microcoryphia, a detritivore, catches one order of magnitude above all the other sites and were considered outliers for the purpose of viewing relative guild abundances. Microcoryphia from these sites were not included in Figure 13. There we find a relative increase in detritivores and decrease in herbivores as we move from the more logged to unlogged areas.

The arthropod guild set with the global site set gave one significant canonical correlation ($F(24,123.31) = 2.51$, $p = 0.001$) as seen in Table 13. The arthropod guild set showed a within-set variance accounted for by the canonical variates of 40% and a redundancy of 26% while the global site set's within variance accounted for was 32% and a redundancy of 20%. Predator, detritivore, and omnivore guilds decreased with increasing logging, soil moisture, and tree cover and decreasing herb cover.

Also in Table 13 the arthropod guild set with the vegetation density set gave one significant canonical correlation ($F(24,123.31) = 1.93$, $p = 0.011$). The arthropod guild set showed a within-set variance accounted for by the canonical variates of 41% and a redundancy of 22% while the vegetation density set's within variance accounted for was 32% and a redundancy of 20%. Omnivore, predator, and detritivore guilds decreased with increasing soil moisture, logging events, shrub distance, and understory distance and decreasing overstory distance.

Table 12.—Pitfall catches of arthropods by guild in each study area.

Guild	Old Growth	Second Growth	Tree Farm
Detritivore	237	101	309
Herbivore	103	182	108
Omnivore	95	153	38
Predator	162	150	71
Total	597	586	526

Note: 119 of the detritivores in the old growth and 275 in the tree farm are from a single sampling site.

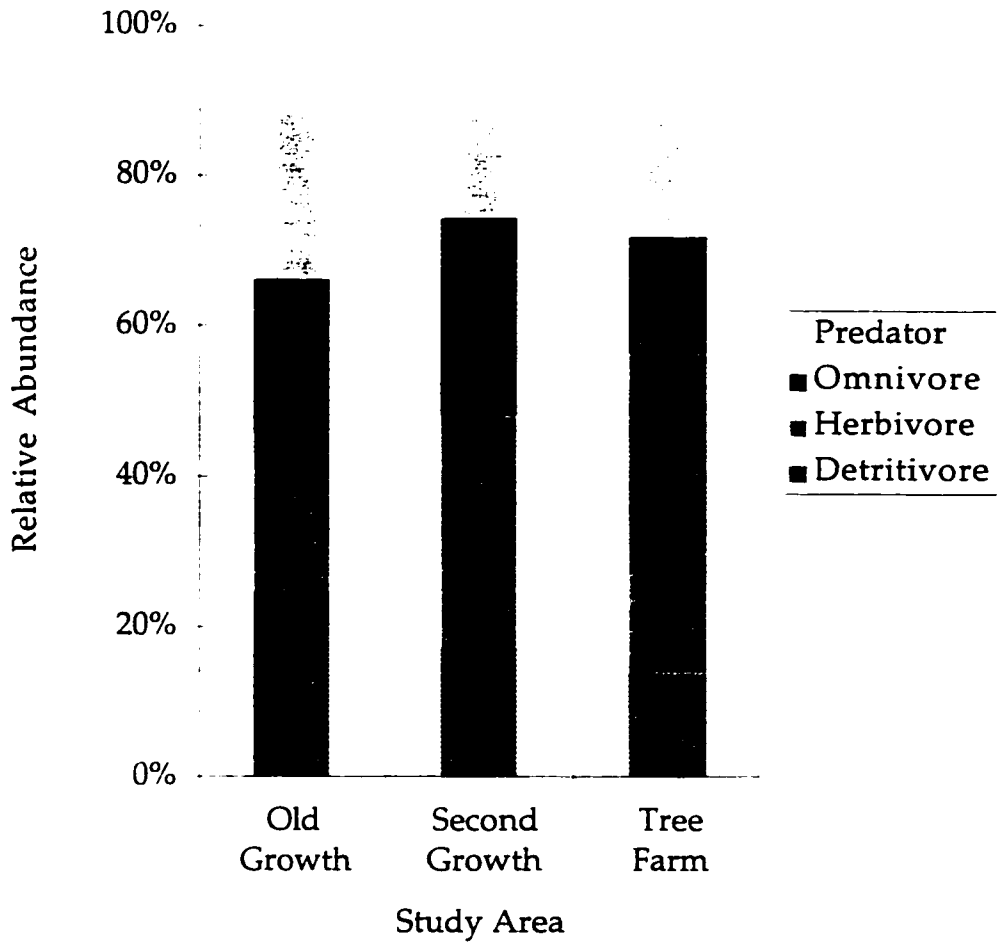

Figure 13.—Relative abundances of arthropods by guild caught in pitfall traps in each study area with detritivore outliers removed.

Table 13.—Canonical coefficients and loadings of variables larger than ±0.3 in the arthropod guild set and site sets

Global Site Set			
Canonical Correlation		0.804	
Squared Canonical Correlation		0.647	
p-value		0.001	
Arthropod Guild		Site Characters	
Predator	-0.783	Herb Cover	-0.673
Detritivore	-0.725	Times Logged	0.669
Omnivore	-0.654	Soil Moisture	0.667
		Tree Cover	0.464
Vegetation Density Set			
Canonical Correlation		0.744	
Squared Canonical Correlation		0.553	
p-value		0.011	
Arthropod Guild		Site Characters	
Omnivore	-0.824	Soil Moisture	0.777
Predator	-0.733	Times Logged	0.724
Detritivore	-0.587	Shrub Distance	0.584
		Understory Distance	0.476
		Overstory Distance	-0.369

Effect of Distance from Trail

No variables or sets of variables relating to spiders, other arthropods, or vegetation appeared to vary significantly with distance from trail.

DISCUSSION

Spider and other Arthropod Diversity

Spider and arthropod diversity and abundance showed significant negative correlations with the number of times a site had been logged. Both spiders and arthropods, in general, benefitted from increased herb cover while spiders also reacted favorably to widely spaced overstory trees and arthropods to decreasing soil moisture.

The negative correlation of diversity and abundance to number of logging events was expected based on past data from the Big Basin area Hoekstra *et al.* (1995) that found significantly lower arthropod predator abundance in areas sampled in the RedTrees tree farm than in the areas sampled in old growth or second growth portions of Big Basin State Park. The Hoekstra *et al.* (1995) study collected arthropods by using Berlese funnels to extract the animals from litter samples whereas this study used pitfall traps yet the pattern of findings is consistent between the two studies.

This finding is also congruous with other studies and experiments showing differences between arthropod communities in undisturbed forests as compared to forests disturbed by logging (Huhta 1971; Puntilla *et al.*;1991; Mciver, Moldendke, and Parsons 1992; Pettersson *et al.* 1995; Simmonds, Majer, and Nichols 1994; Pajunen *et al.* 1995; Schowalter 1995; Økland 1996; Niemalä 1977) or other disturbances such as floods (Clark and Grant 1968; Uetz 1976; Uetz 1979; David et al. 1991; Hurd and Fagan 1992; Sundberg and Gunnarsson 1994). These studies on soil arthropods generally find changes in guild structure, diversity, and abundance with increased logging.

An interesting difference, however, is that Mciver, Moldendke, and Parsons (1992) and Pajunen *et al.* (1995) had the lowest overall abundance and species richness in old growth condition and the highest in clearcuts or plantations. However, certain species abundances were counter to this overall trend. The overall pattern found in these two studies is contrary to the data from this study that fewer individuals and species were caught in logged sites.

Their studies differ in three ways from this study that may partially account for such differences. First, both of these studies used pitfall traps with ethylene glycol, a sweet flavored preservative that may be an attractant, whereas traps in this study had water and soap to reduce repellent or attractant properties and to avoid the release of toxic substances on State and private lands (see Uetz and Unzicker 1976 on pitfall trap design).

Second, the Mciver, Moldendke, and Parsons (1992) study included sites that had been clearcut no more than 30 years ago and the Pajunen *et al.* (1995) study included plantations that were presumably clearcut on a short rotation whereas only selective logging had occurred at the Red Trees tree farm since the initial clearcut at the turn of the century. Clearcutting may result in conditions that favor those species more readily caught in pitfall traps as seen by large wandering spiders preferring open habitats while sit and wait web spiders prefer closed, mature habitats and are less likely to wander into a trap (Topping and Sunderland 1992; Topping 1993).

Finally, Oregon Douglas-fir and Finnish Tiaga may have fundamental ecological differences from California redwoods. Redwoods, for example, have a growth cycle on the order of five hundred to one thousand years and may live as long as two thousand years (Fowells 1965; Zinke 1988; Kricher and

Morrison 1993) whereas Douglas-fir mature in 100 to 175 or so years (Fowells 1965; Kricher and Morrison 1993). Differences between the Oregon and Finland litter spider studies and the California studies may be due to ecological disparities, dissimilitudes in logging treatments, or differences in sampling methods.

Spider Guild Structure

Research in Oregon Douglas-fir forest (Mciver, Moldendke, and Parsons 1992) and Finnish Tiaga (Pajunen *et al.* 1995) that compared litter spider communities in old growth and clearcut or plantation conditions found that spider communities differ generally with larger cursorial spiders such as gnaphosids and lycosids dominating in cut or intensively managed conditions and web builders such as linyphiids more present in mature, unlogged forest stands.

This research in the Santa Cruz redwoods supports these findings. Although all guilds were more abundant in unlogged, mature stands, open sites such as those disturbed by tree falls are dominated by large wandering spiders. Undisturbed sites with widely spaced overstory trees tended to have more small web builders, such as *Ceratinops inflata*, and larger sheet web builders that would require a more stable habitat for their webs, especially the agelenids who build semi-permanent webs (Foelix 1996; Levi and Levi 1990). Guild structure then can indicate where a restoration site is in relation to an old growth area. We can expect to see an overall relative increase in nocturnal hunters as an area matures, keeping in mind that certain patches will deviate from this trend.

Web Counts

Webs, especially sheet webs, were less frequent in open, steeper, herbaceous sites with thin litter layers. Sheet webs are built directly on the litter layer so a thinner layer would provide less structure to build on. Also, the webs are used as a trapping surface where an insect lands on the flat surface of the sheet and while the creature negotiates the unfamiliar and entangling substrate, the resident spider rushes forth from its retreat and captures the enervated insect (Foelix 1996). Such a trap would be expected to be less stable and less successful on a slope and so perhaps these spiders tend to build their webs on more level surfaces. Increased tree cover also appeared related to increased webs. If these spiders are catching herbivores, increased tree cover may be providing more food and shelter for prey items as herbivory becomes arboreal during the succession from openings due to tree falls to older, closed canopy sites (Hurd and Fagan 1992).

Arthropod Guilds

Just as Hoekstra *et al.* (1995) and Schowalter (1995) found, the greatest effects of logging appeared in predator and detritivore guilds as well as with the ants, who in this study were classified as omnivores. Increases in guild abundance may relate to a successional progression or disturbance gradient from young, harvested stands to older, unlogged stands with mature, dense understory and shrub layers. This progression includes a movement of herbivory from the forest floor to upper canopy layers and may explain the absolute and relative increases of litter predators and detritivores as fallen

wood and leaves become the more prevalent food source for litter layer arthropods (Hurd and Fagan 1992). As with spider guilds, it appears that changes in arthropod guilds can indicate forest conditions, with detritivores and predators increasing relatively as an area matures or recovers from logging.

Comparison to Canopy Studies

The studies of Douglas-fir canopies (Schowalter 1995) and northern European boreal forest canopies (Pettersson *et al.* 1995) in logged and unlogged conditions are consistent with the California redwood litter studies in finding lower spider abundances and diversity in logged conditions. While canopy and litter spider communities are separated by space, they are connected through their predation on herbivores and detritivores (Crossley 1977) although they may show a different pattern of response to logging disturbances. In particular, the Schowalter (1995) and the Mciver, Moldendke, and Parsons (1992) studies were done in the same forest, the H. J. Andrews Experimental Forest in central Oregon, and found different responses between the canopy and the litter communities. In Mciver, Moldendke, and Parsons (1992) pitfall catches were highest in recently cut areas while in Schowalter (1995), abundances were highest in mature areas. Such differences could be explained by a movement of the spider community from the ground to the canopy as the forest matures (Hurd and Fagan 1992) especially when recovering from a clearcut where the canopy is removed entirely. These differences suggest the importance of a study of redwood canopy arthropods in logged and old growth conditions to see if they differ in response as compared to the litter community.

Potential Arthropod Indicators

One useful indicator of ecosystem recovery is the return of old growth specialists to an area or an increase in species who prefer old growth habitats (see Table 14). There were two genera of spiders that only appeared in the never logged condition that could be watched for specificity in their habitat preferences. One is *Phrurotimpus* sp. (Figures 14 and 15) in the Liocranidae (formerly in Clubionidae) of which five were found in three different never logged sites of the Douglas-fir-madrone-oak complex. The other is *Lepthyphantes* sp. in the Linyphiidae. Two were found at two different never logged sites. One site had heavy tree cover from redwoods and Douglas-fir and no herb cover and the other site was similar to the Douglas-fir-madrone-oak complex, although it bordered on a redwood dominated site.

The most abundant spider overall was *Zelotes* sp. (Figure 16), a nocturnal hunter in the Gnaphosidae family that appeared to show a preference for sites dominated by unlogged Douglas-fir-madrone-oak complexes and that tended to be more open and herbaceous. It did not often appear in pure redwood stands. Another abundant spider was *Xysticus* sp. (Figure 17), a diurnal hunter in the Thomisidae family, that tended to be more general in its habitat preferences although its greater occurrence was in unlogged sites. *Ceratinops inflata* of the Linyphiidae family was a common web builder found in equal proportions in old growth and second growth but much less in the tree farm area.

The only non-native spider found, *Segestria* sp., a species found in *Eucalyptus* sp. forests in Australia (Ubick, personal comment), occurred in a tree farm area. The tree farm was observed to have exotic plants such as

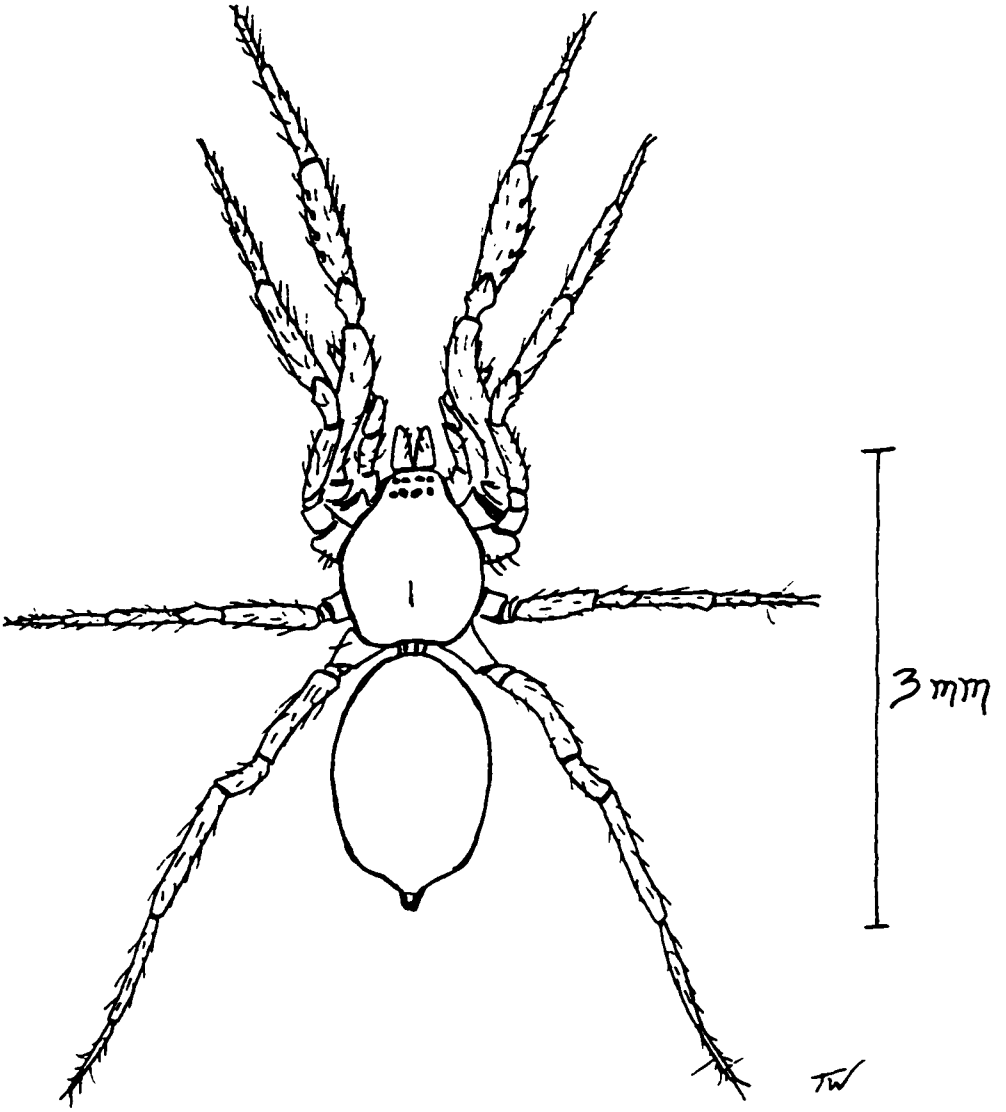

Figure 14.— *Phrurotimpus* sp. found only in old growth area.

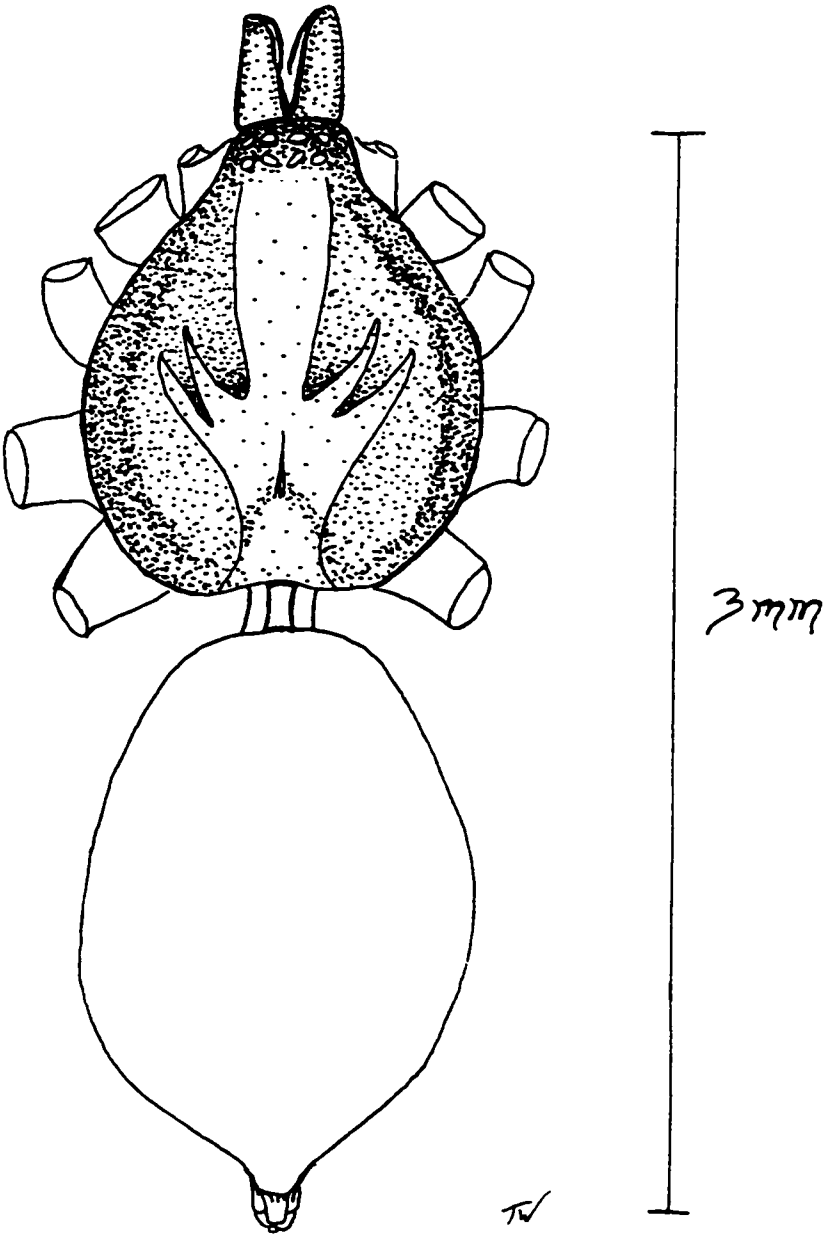

Figure 15.— *Phrurotimpus* sp. with carapace pattern.

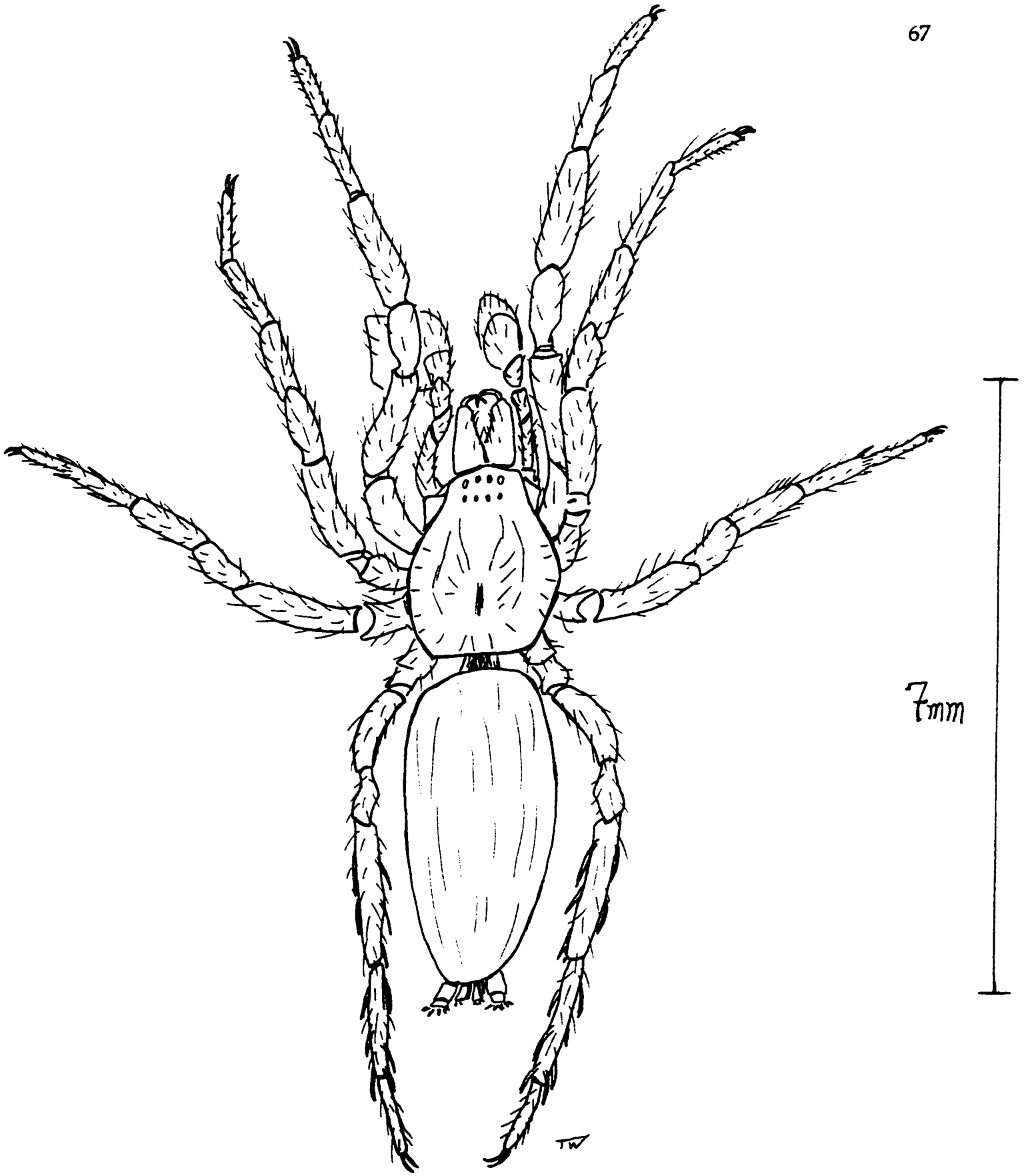

Figure 16. — *Zelotes* sp.

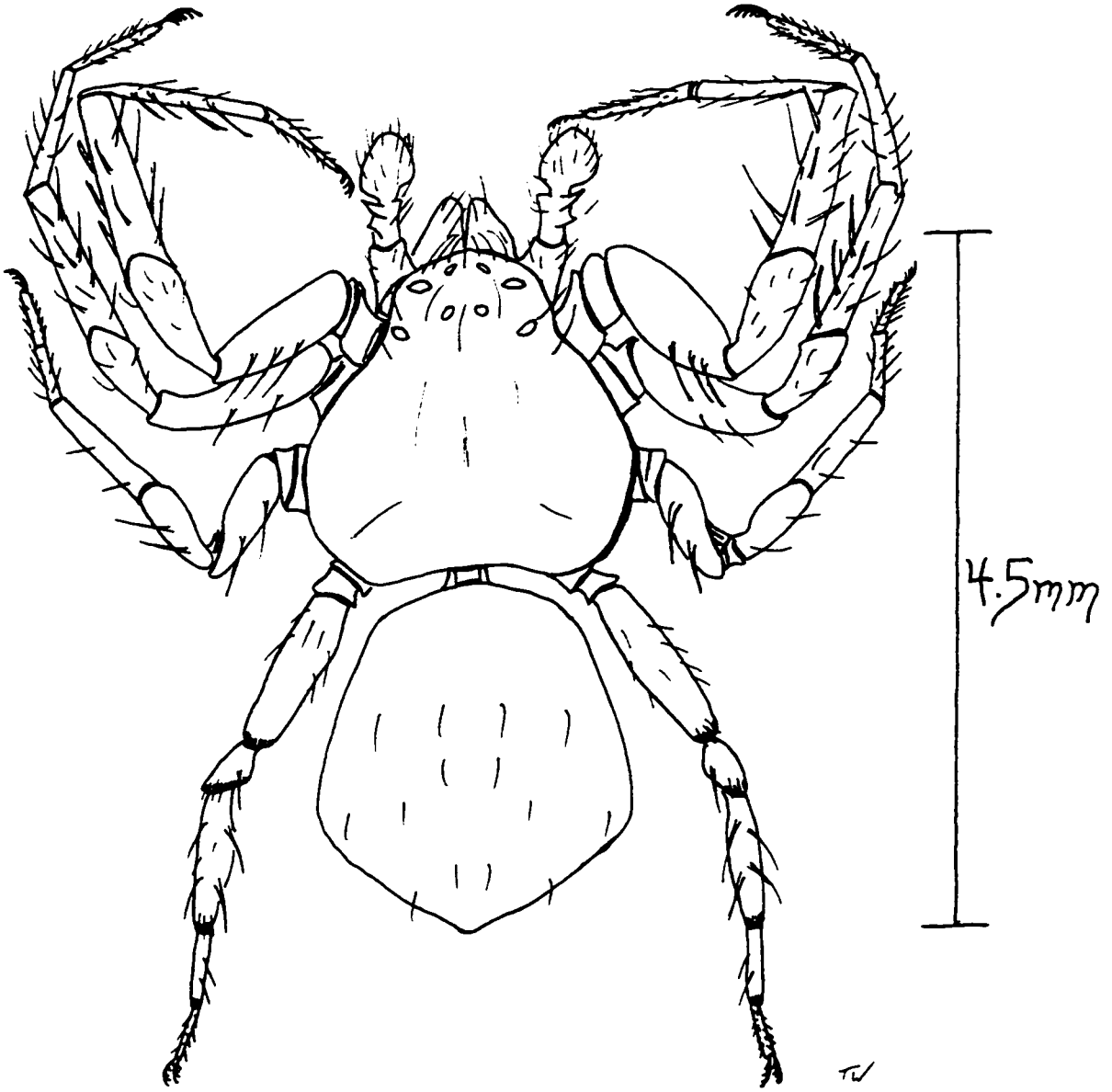

Figure 17.— *Xysticus* sp.

french broom (possibly *Genista monspessulana*) and foxglove (*Digitalis purpurea*) although no *Eucalyptus* sp. and none of these exotics occurred within any of the sampled sites.

Some harvestmen (order Opiliones) also showed sharp increases in unlogged sites such as individuals in the Phalangidae family.

Finally, after stepping on a nest of stinging Hymenopterans (bees), a careful observation of the location of such nests near the study sites was made. Four were found to occur in the old growth study area, one in the second growth area, and none in the tree farm area.

Table 14.—Pitfall Catches of Potential Arthropod Indicators by Area

Family	Genus	Guild	Old Growth	Second Growth	Tree Farm	Total
Erigonidae	*Ceratinops inflata*	W	7	7	2	16
Gnaphosidae	*Zelotes* sp.	N	20	10	5	35
Liocranidae	*Phrurotimpus* sp.	D	5			5
Lynyphiidae	*Lepthyphantes* sp.	W	2			2
Phalangidae			13	2	1	16
Segestridae	*Segestria* sp.	D			1	1
Thomisidae	*Xysticus* sp.	D	11	5	4	20

Note: D = diurnal hunters, N = nocturnal hunters, W = web builders

Limitations

Generalization of Findings

The small scale of this study cautions against prematurely extending these findings beyond the areas measured. It cannot be claimed that these findings apply to all forests, or to all redwood forests, or even to all stands in the Santa Cruz Mountains. Rather, these observations should be taken as suggestions for future research and assessments.

In addition, the limited time frame of the trapping effort allows for the possibility of aberrations in climate or other factors to influence the results. For instance, Table 15 shows rainfall and temperature measures in the June that sampling occurred in addition to the two previous Junes.

Table 15.—Rainfall and Temperature Comparisons for 1995, 1996, and 1997.

Year	Total Rainfall		June Rainfall		June Temperature	
	(inches)	(cm)	(inches)	(cm)	(°F)	(C)
1995	64.23	163.1	1.11	2.82	63.7	17.6
1996	84.89	215.6	0.04	0.10	66.5	19.2
1997	57.98	147.2	0.25	0.64	65.9	18.8

Sources: National Oceanic and Atmospheric Administration and the Santa Cruz Sentinel

The past years were wetter than the year of this study and have had an unknown effect on arthropod populations. Ultimately, only replication of this study in future years will reveal if such influences confound the data. This study has helped provide a baseline to which future studies can compare and so be useful even in the presence of confounding climatic conditions.

Pitfall Traps

Pitfall trapping, while widely used, can suffer sampling bias (Topping and Sunderland 1992; Topping 1993). Catch abundance is related to variations in catchability by species and sex and influenced by vegetative structure. Also, species caught do not necessarily reproduce in that area (Niemelä 1997). However, recommendations that such data be used only for relative comparisons between habitats (Uetz and Unzicker 1976; Topping and Sunderland 1992) have been followed in this study.

Web Counts

In addition to pitfall traps, the use of a supplementary method was employed—web counts. The procedure used, while standardized within the study, is not universally employed and so limits the ability to compare these results to other work. It is also unknown how efficacious this particular method was as opposed to another technique of web counting (Southwood 1992). For instance, herb cover, cloud cover, and time of day all affected the ability to detect webs. The influence of these factors may be reduced by employing a more active search regime or using a transect technique along with replications of sampling efforts. Also, categorization of webs was very

broad and the technique may profit from making finer distinctions in web architecture.

The Herbivore Guild

Herbivores may not have appeared in the analysis perhaps due to a lack of analytic resolution in the definition of this guild. It could be that separating herbivores into foliar and xylem feeders or some other scheme may be a more appropriate level of analysis. However, herbivores also may not have appeared simply because their abundance is not related to the factors included in this analysis.

RECOMMENDATIONS

A consistent finding of this project was the negative association between the number of logging events and the abundance and diversity of spiders and other arthropods. This finding occurred even though the tree farm sampled in the study uses selective harvesting techniques that are considered a model for sustainable redwood forestry (D. Hermman, personal comment). While the tree farm may be sustainable with respect to redwood biomass and financial integrity for the near future, findings from this study and from Hoekstra *et al.* (1995) show that these forestry techniques do not result in the maximum diversity or abundance of forest floor arthropods. These arthropods are important in decomposition and nutrient cycling (Ausmus 1977; Crossley 1977; Reichle 1977; Van der Drift and Jansen 1977; Wallwork 1983; Anderson *et al.* 1985; Verhoef and De Goede 1985; Visser 1985; Moldenke 1990; Wood 1995; Coleman and Crossley 1996). Events that disrupt these communities could be expected to disrupt these cycles that are needed for the sustenance of the primary production that forms the basis of the forest.

Defining Sustainable Forest Management

Forestry in any of its current forms has major impacts on the forest system and terms such as "sustainable forestry" are still waiting a stable definition and realization. For some, "sustainable development (or sustainable forest management) might well be regarded as a mandala—a ritualistic symbol or icon of some desired but ill-defined future", while others

"see sustainable forest management as a myth designed to justify continued timber production" (Ferguson 1996, 111). To avoid confusion, Kimmins (1987) noted that foresters should be explicit about sustained yield harvesting as opposed to timber mining. For instance, while a tree farm may be managed for a sustained yield and so be considered a renewable resource, "neither the 1000 year old redwoods in California...nor the 300 year old oaks in France...can be considered as renewable resources" (Kimmins 1987, 476) as the time scale of regrowth so exceeds the human life span and the discount rate that once ancient trees are cut, they are effectively destroyed for a personal and economic eternity.

Attempts to accurately define sustainable forestry traverse a variety of ideas and worldviews from the biocentric to the anthrocentric. In a text striving for such a definition, Johnson noted "it is no longer enough simply to sustain timber yields if it is ultimately the forest that one wants to sustain" (1993, 11). Noss (1993) stated that sustainable forestry must include an appropriate time scale and a specific goal of what proportion of ecosystem structure, function, and composition should be maintained in the exploited forest as compared to a standard defined by an unexploited forest. Foresters such as Salwass, MacCleery, and Snellgrove put more emphasis on technological solutions and human desires suggesting that "high productivity sites...should be managed with state-of-the-art efficiency in certain places to sustain the production of resources desired by people, thus meeting human needs with minimal effects on more fragile sites and sensitive species" (1993, 78). Economists such as Ferguson (1996) put their emphasis on institutional management to influence supply and demand through enforceable timber cutting rules and sanctions for violations, market pricing that captures

economic and ecological costs, and clearly defined property rights. Despite differences in emphasis, all agree that a main goal of sustainable forest management should be to maintain that which cannot be replaced on a human or geologic time scale.

To this end, it must be realized that land managed for timber extraction is not equivalent to large expanses of intact, mature, unlogged forests for the maintenance of forest communities and processes. Humans have not mimicked nor recreated forest processes, communities, nor replaced extinct species and we cannot substitute logged land for wilderness at any ratio. Large tracts of undisturbed lands are needed to preserve genotypic diversity, to maintain the integrity of communities and processes we do not yet understand, to provide the opportunity for future inhabitants to experience these areas, and to serve as a control for our management experiments (Harris 1984; Kimmins 1987; Barbour *et al.* 1993; Noss 1993; Trombulak 1996).

Maintaining Redwood Forests

In planning redwood forest management, the time scale and the heterogeneity of the redwood forest must be considered. Redwoods mature in 400 to 500 years and may live 1000 to 2000 years (Fowells 1965) while Douglas-fir mature in 100 to 175 years and may live 500 to 1000 years (Fowells 1965; Kricher and Morrison 1993). Schowalter (1995) showed that Douglas-fir forests in particular may regain old growth characteristics 150 years after logging. Because of this longevity, Zinke (1988) and Barbour *et al.* (1993) suggested 500 to 1000 year management plans for redwood and mixed evergreen forests. Further, Harris (1984) proposed to manage timber lands as

patches cut in rotations around an inviolate core that would allow for all seral stages to be present at any given time in order to maximize habitat. These time scales to recover from logging and reach maturity suggest that we would need to leave redwood stands untouched for centuries to millennia to allow them to fully regain the characteristics of mature forests.

While this may be possible in theory, economic forces act against such a purely biological approach. Redwood growth peaks before 35 years and redwoods can attain a height of 100 to 150 feet in 50 years (Fowells 1965). Growth slows after this so that after a few to several decades the annual incremental volume added declines below the rate of interest earned on the cash that can be obtained from the sale of the cut tree. For example, Ferguson (1996) pointed out that a discount rate of 4% brings the present value of a harvest about 60 years in the future to zero. Thus, a land owner has no financial incentive to allow forests to mature ecologically. Having economic incentives align with ecological goals would require institutional modification either of prices through taxes to include external costs of timber harvesting or direct regulation of harvesting regimes.

Also, redwood forests are often a mosaic of pure redwood stands blending into tanoak into Douglas-fir-madrone-oak complexes with each of these components having their own time scale and community composition in addition to changes in species composition with changes in latitude. Future studies may benefit from focusing more on sampling from these different communities and from different vegetative layers to try to determine what decisions can be applied broadly across communities and which need to be made more specific to particular forest patches.

Redwood Forest Monitoring

Forest management, especially for timber production, could benefit from expanding the set of parameters it examines when making decisions. There are still questions as to all the effects of human impacts on the forest, and managers should look at as many relevant factors of forest ecology as feasible to assess changes in time and evaluate the functioning relative to undisturbed stands. These measures could include: soil moisture and nutrients; stream sedimentation; basal area of dominant trees; species composition of understory, shrub, and herb layers; critical habitat structure such as litter, logs, and snags; bird and mammal surveys; and surveys of certain guilds of interest such as herbivores, detritivores, and predators; and monitoring for rare, endangered, or indicator taxa.

This researcher suggests that the monitoring of redwood forests can and should include arthropods. Web counting along with other quick and nondestructive techniques such as visual searching, litter sifting, and brush beating, are favored for gross abundance comparisons that do not need taxonomic detail below guild, order, or family. Consistent with Williams and Gaston (1994), this study found a few species that might be related to old growth, but in general, showed that guild, order, or family classification yields sufficient resolution to make comparisons between a baseline area and areas managed for restoration or other uses.

It is in the interest of all to maintain the integrity of our redwood forests. To this end, we must be clear on our goals and boldly use our collective observations to intelligently interact with the land.

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IMAGE EVALUATION
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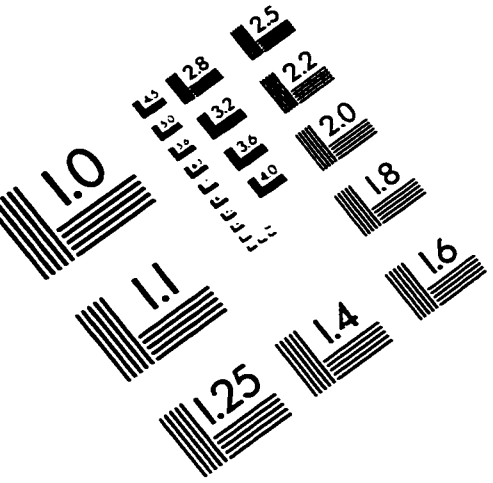

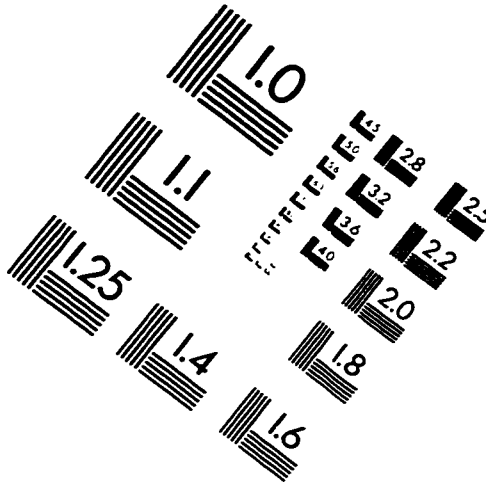

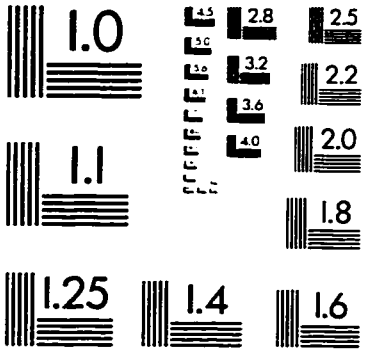

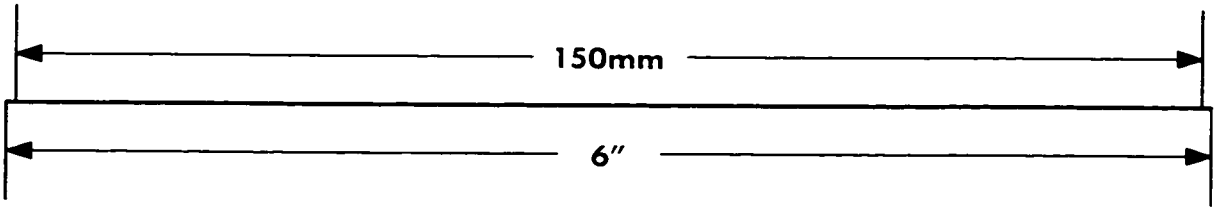

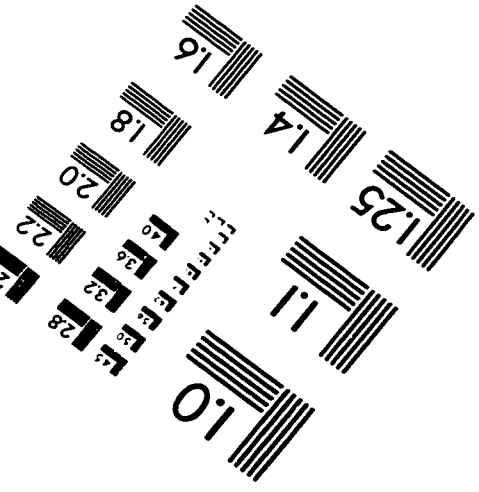

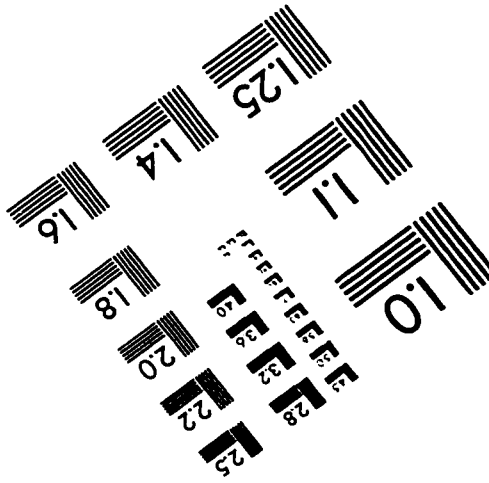

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